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STUDIES ON THE MOVEMENT OF SOLUTIONS THROUGH FLATHEAD-CAUSED SCARS IN THE SAPWOOD OF PONDEROSA PINE

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by
K. A. Salman and J. W. Johnson
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March 28, 1940

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Forest Insect Laboratory
Berkeley, California
March 28, 1940

STUDIES ON THE MOVEMENT OF SOLUTIONS THROUGH FLATHEAD-CAUSED SCARS IN THE SAPWOOD OF PONDEROSA PINE

APPROVED BY:

J. M. MILLER
Senior Entomologist, In Charge

SUBMITTED BY:

K. A. SALMAN
Entomologist

J. W. JOHNSON
Agent

TABLE OF CONTENTS

Introduction	1
Objective of Study	2
Definitions	2
Literature Pertinent to the Study	2
Preliminary Experimentation	3
Technique	5
Materials	6
Preparation of Samples	8
Kinds of Samples	11
Methods of Storing Samples	11
Basis for Results	12
Basis for Analysis and Interpretation	12
Significance of Results	13
Results	13
Discussion of Results	14
Summary of Report	33
Bibliography	34
Supplementary Tree Growth Information	36

ILLUSTRATIONS.

Text figure 1.	Growth Patterns of Trees Used as S Sources of Wood for Tests.	9
Text figure 2.	Conductivity of Annual Rings in Control and Scarred Samples	15
Text figure 3.	Diagrammatic sketch of the Conduction Patterns in the Annual Rings of a Control and of a Scarred Sample.	18a
PLATES 1 to 17		following 38

STUDIES ON THE MOVEMENT OF SOLUTIONS THROUGH FLATHEAD-CAUSED SCARS IN THE SAPWOOD OF PONDEROSA PINE

INTRODUCTION

The purpose of this report is the description and presentation of results of a study carried out during the summer of 1939 at Hackamore in Modoc County, California, by the Bureau of Entomology and Plant Quarantine. The work was begun by Dr. A. S. West, Jr., but following his resignation from the Division of Forest Insect Investigations, it was continued by J. W. Johnson under the direction of Dr. K. A. Salmon.

The problem under consideration is a part of a broader study of the biology and host relations of the California flathead borer, which has been in progress at the Hackamore Field Laboratory during the past four years (Salman and Bongberg 19, West 20, 21, 22, 24, 25.). As a result of work to date the general biology of the species is now comparatively well known. One of the distinctive characteristics of its biology is the existence of a lengthy "incipient" larval stage during which the tiny larva lives in the cambium region and causes injuries which result in the production of lengthy scars in both the phloem and sapwood as a result of a reaction on the part of the living, infested host tree.

The histological nature and manner of formation of the sapwood scars was first investigated in detail by West (24). Partly in consequence of West's work, as well as because of certain observations made in connection with tests of the injection of copper sulfate solutions in standing trees, it seemed desirable to subject these sapwood scars to tests which might give evidence whether they impair one of the functions of the sapwood, i.e., the conduction of water. It was hoped that the evidence secured would contribute to a better understanding of the problem of the host-insect (parasite) relationships.

Acknowledgements

The authors gratefully acknowledge their indebtedness to the many people who contributed to this study. Dr. A. S. West, Jr. conducted many of the preliminary tests in which Mr. R. F. Anderson assisted. Mr. J. M. Miller's many general and specific suggestions and criticisms, and Mr. J. E. Patterson's suggestions in the preparation of figures and plates were of considerable help. N. Y. A. students from the University of California helped in preparing the graphs. The whole-hearted cooperation of the Modoc Forest Service administrative force and of Mr. Frank Kaufmann in making available the services of CCC enrollees from the Hackamore CCC Camp was an important factor in conducting the field work at the Hackamore Laboratory.

OBJECTIVE OF THE STUDY

The problem under investigation was that of determining if injuries to the sapwood of living ponderosa pine trees, which result from the feeding of small larvae of the California flathead borer (Melanophila californica Van Dyke) in the cambium region, interfere with the movement of solutions in the wood.

DEFINITIONS

The following definitions are given to clarify the manner in which certain words are used in this report.

Galleries: As used by West (20, 21, 22, 24, 25) and in this report, this word denotes the winding welts or ridges of wood scar tissue in the sapwood. These ridges are produced by the tree as a response to injuries which were caused by the feeding activities of the small "incipient" larvae in the cambium region.

Scars: An inclusive term including galleries, pitch blisters, pitch pockets, pits and similar injuries. Pitch blisters and pitch pockets are produced at the spots where larvae are killed by pitching out. Pits, usually in young or fast-growing trees, also mark the spots where individual larvae died. In all cases seen thus far, pitch blisters, pitch pockets, and pits occur at the terminal end of the galleries with which they are associated.

Conductivity, conduction, conductive: These terms are applied only as expressions of the behavior of the wood with respect to the movement, under pressure, of the staining solution through it. Annual layers of wood which allowed full penetration of stain through them have been termed fully conductive. The conduction is good; or the layers have a high conductivity. When the distribution of the stain in the annual layers indicated a restricted movement of the staining solution through them, the words are used with the diminutives or negatives in the same sense.

LITERATURE PERTINENT TO THE STUDY

As a background for carrying on the study and the analysis of the data, an extended series of publications dealing with wood structure, plant and tree physiology, tree growth analysis and methodology were consulted.

Wood Anatomy: Eames and McDaniels (10), Record (18) and Büsgen and Münch (4) were found of particular value in understanding wood structure and the anatomy of trees.

Physiology: For physiological background the following references were valuable. Dixon (8, 9), Maximov (16, 17), and MacDougal (15) were consulted for information on hypotheses for the ascent of sap, the fundamentals of water relations in plants, and the behavior of solutions introduced into the transpiration streams of conifers. The discussions by Curtis (7) and Crafts (5, 6) on the relations of sapwood to the translocation of solutes, and a presentation of recent information on plant physiology by Barton Wright (3) have given a better understanding of the information in this field.

Tree Growth Analysis: In growth ring analysis, the methods developed by Douglass and stated recently by Glock (12) have been referred to. Of particular pertinence was Keen's (14) paper on the growth sequence of pines in the general region in which the present study has been conducted. Antev's (1) report on tree growth and climate in nearby Great Basin areas confirmed Keen's results.

Methodology: For selection and evaluation of the method employed in this conduction study, the methodology in the literature was referred to, especially MacDougal's work (15) with pines. However, the requirements of the problem necessitated the development of a special technique which has been described recently by Johnson (13). Ho, Melhus, and Munsey (12) have proposed a method for determining quantitatively the rates of conduction in galls. That method, although it has not yet been used in this study, may be found to be useful in future work.

Flathead Biology: The study has its foundation in the work of Salman and Bongberg (19) and of West (20, 21, 22, 23, 24) who have determined the species of insect concerned and have described its general biology and the nature of its injury to the ponderosa pine tree.

PRELIMINARY EXPERIMENTATION

Copper Sulfate Injection: In connection with the analyses of trees that had been injected with copper sulfate solutions during August, 1937, in experiments to determine if timber values in high risk trees could be preserved until utilization could be effected, it was observed that the presence of incipient galleries in portions of some of the experimental trees seemed to be associated with a break up of the conduction stream (West 25). It was thought that the incipient galleries might play some part in breaking up the conduction stream by restricting the movement of solutions in the wood. Accordingly the possibility of utilizing copper sulfate solutions or stain injections in living infested trees to determine the effects of the incipient galleries on conduction was considered in preparing the 1938 work program of flathead project. It was decided, in the light of experience with the copper sulfate injections, that the injection of standing poles, or the stepping of small trees in buckets of stain, would not be as satisfactory as other methods for the following reasons:

1. It is impossible to secure comparable healthy and infested trees. The characters associated with an unhealthy condition and incipient infestations markedly affect conduction and make comparisons difficult, if not impossible.

2. As the conduction pattern in individual trees seems dependent on numerous biological and physical factors, it would be impossible to segregate the effects of the incipient galleries on conduction from effects produced by other factors.

3. It seemed apparent that any method that did not eliminate all variables, except the presence or absence of incipient scars in the wood, probably would give results representing the effects of composites of factors rather than of the galleries alone.

Stepping of Trees in Buckets: The above objections have been partially substantiated since (1939) by West in tests on one healthy check tree and one tree on which flathead broods had been established by forced attacks extending over three seasons. Both were cut, stepped in buckets of "scarlet red" aniline stain for a period of 24 hours and subsequently examined in detail to determine the course of the stain in each tree. While it was found that the uninfested tree took up more stain than did the infested tree and that the stain penetrated farther up the trunk in the check than in the infested tree, it was impossible to state, when all variables were considered, if or what portion of the differences were due to the presence or absence of the incipient injuries.

Injection of Large Blocks: In his memorandum for files of August 3, 1938, Dr. F. C. Craighead suggested ""that the use of stain or copper in the living trees can be used for further study of this problem" (of the effects of incipient scars on conduction). Later in that season, when press of other work on flathead biology allowed, a few tests were run involving the injection of three foot blocks cut from infested and uninfested poles. Stains were forced through these blocks under given pressures. However, these few tests gave inconclusive results.

Injection of Small Blocks: In the light of the early tests, it was apparent that attempts to deal with standing trees or relatively large sections of trees would be unsatisfactory because of the many variables related to size, physiological condition, disposition, number, and character of scars, effects of roots, branches, leaf surfaces, conducting tissues and many other factors. Accordingly, it was thought that the best method would be to isolate the scar effects from other variables by restricting the field of study to testing the effects of individual scars in small blocks of wood of equal size and prepared and treated in the same fashion. During the 1939 season small wood blocks were used in all but one test.

TECHNIQUE

With the choice of the individual scars as the basis for study, further testing was directed towards perfection of a technique for staining wood samples.

Choice of Staining Materials: Numerous tests were run to determine which staining substance best fitted the requirements of this work. When aniline stains, such as scarlet red, water green, and methylene blue were forced through the blocks under pressure, the results consistently indicated a restriction or blocking of the movement of solutions through the scar tissues when the blocks were split and examined immediately after the injection. However, subsequent passive movement of the stain through medullary rays and wood tissues, apparently due to the high diffusibility of the stain, usually obliterated the picture of obstruction of the dynamic movement of the solution while it was under pressure. In order to demonstrate to others that the blocking actually occurred it was considered necessary to stop the spread of the stain soon after the pressure was released and before the passive spread of the stain modified the picture of conduction. To this end, further testing of a staining medium more suited to the needs of the study was undertaken.

The results of these tests have been described by Johnson (13) in a separate report. The perfected method used a two and one-half percent solution of silver nitrate in twenty percent ethyl alcohol as a stain.

Selection of Method: A standard procedure - which was decided upon arbitrarily after numerous tests were run under varying conditions - was adopted for use in the 1939 work. That procedure was as follows.

The solution used in the injection work was stored in a glass bottle attached to a rafter of the field laboratory building some distance above the floor. It was applied to the wood sample by siphoning it off through rubber tubing, one end of which was slipped over the end of the wood sample. The solution was under a gravity pressure of about one-quarter atmosphere at the point of attachment of the tube to the sample. A clamp was used to control the injection of the solution into the sample. Most of the samples were injected for a period of two minutes. After the injection, the sample was removed from the tubing, split longitudinally perpendicular to the cambium surface, and the pieces dropped into a photographic developer solution for one-half minute. They then were transferred to an acid-fixative "hypo" for one minute and washed in running water for ten minutes. After this treatment they were removed and dried as rapidly as possible. This treatment was sufficient to precipitate the silver solution on the exposed surfaces of the wood sample, fix it, and preserve for future reference the picture of conduction in each sample.

Variations in Application: In treating the samples in trees 39-34, 39-38, 39-42, 39-43, the timing was as described above. In treating samples from tree 39-37, the silver solution was applied for but one minute because of the high conductivity of the wood for the stain.

The stain was forced through the majority of the samples in the same direction as the sap flows through the wood, i.e., from the lower to the upper end. In the samples from tree 39-38, however, the stain was forced through in a reverse direction. The numbers treated in these two ways are shown in table I.

MATERIALS

The types of materials and number of trees used as sources of wood for the numerous tests are shown in table I. Trees numbered 39-13, 36-20, 39-27, and 39-30, were used as sources of wood in the first experimental trials during the development of the technique.

Variations in Wood: Tests with dried, well seasoned wood showed that that type of material had a low conductivity towards the stain. The dry wood, moreover, over a period of time, showed a greater conductivity of stain in the inner layers in the samples. Wood that had been cut for twelve days was much less conductive than green wood freshly cut from living trees or preserved for a short period of time under conditions that seemed to preserve the fresh state satisfactorily. In contrast to dry wood, the fresh green wood was most conductive in the outermost annual layers.

Choice of Wood for Study: Fresh green wood was selected as the material for study in order to reduce the possibility or amount of changes that might occur after cutting and before injection was undertaken. The wood could then be expected to be in a condition closer to that which it had in the living tree. The differences between conduction in wood of different trees or parts of trees could then be regarded as due chiefly to differences between the trees, rather than due to events affecting the wood subsequent to its removal from the tree.

Samples from tree 39-34, 39-37, 39-38, 39-42, 39-43, and 39-44, were used for the remainder of the tests. Tests made on the wood of the first five of these trees form the basis of the results given later. Attention now will be directed largely to these five trees.

Ring Complements of the Five Test Trees: The first criterion used in the selection of the trees for tests was that each should possess a full complement of annual rings through the spring wood of the current (1939) season. This was considered ample indication that the tree was living and functioning at the time it was selected as a source of wood. Plates 1 to 9 illustrate the growth sequences of all five trees.

TABLE 1. MATERIALS USED IN STUDY

Tree No.	Living Larvae per sq. ft.	Condition of Wood	Sequence of Sample Nos.	Number of Samples			Number Injected		Stain
				Controls	Scarred	Total	Forward	Reverse	
39-13	undetermined infested	dry, seasoned	1-36,44	27	10	37	37	-	Aniline
36-20	18.5	fresh, green	37-43,45	3	5	8	8	-	Aniline
39-27	12.5	cut 12 days	46-48	-	3	3	3	-	Aniline
39-30	undetermined infested	less than 24 hrs. old	49-66	2	16	18	18	-	4 Aniline 14 silver
39-34	9.1	fresh, green 48-72 hrs. old	67-156	19	70	89	89	-	all silver
39-37	10.9	fresh, green 48 hrs. old	157-219 minus 159, 182,212	14	46	60	58	2	silver
39-38	17.8	fresh, green 48 hrs. old	220-280 minus 234	14	46	60	-	60	silver
39-42	undetermined infested	fresh, green 6,28,52 hrs. old	282-287 294-299 312-317	3	15	18	18	-	silver
39-43	not infested	fresh, green 6,28,52 hrs. old	288-293 300-311	-	-	18	18	-	silver
39-44	undetermined infested	standing tree	281	-	1	1	1	-	silver
Total 10				82	212	312	250	62	

In establishing the fullness of the growth complement, the ring sequence of each tree was cross-dated with the master sequence for the Modoc and neighboring areas as developed by F. P. Keen (14). The graphs of the growth sequences of the five trees are plotted with Keen's graph in text figure 1. The growth sequence of tree 39-43 is derived from an average of two cores taken at breast height as that tree was not felled. The graphs of the growth sequences in the other trees are constructed from averages of measurements along four radii (North, South, East, West) of cross-sections of the trees in the upper bole region. The measurements are uncorrected for normal decline in growth due to increase in age. Without making that correction, it is evident, in comparison with the reproduction of Keen's master sequence, that the trees used in this study were following the general growth pattern characteristic for trees in this area during the forty-year interval which the graph covers.

Infestations in the Test Trees: The second criterion for selection of trees was the presence or absence of living flathead incipient larvae. Four trees having active infestations in the incipient stage were used as sources of flathead-scarred wood. The average infestation in three of those trees is given in table 1 in terms of living larvae (not total scars) per square foot.

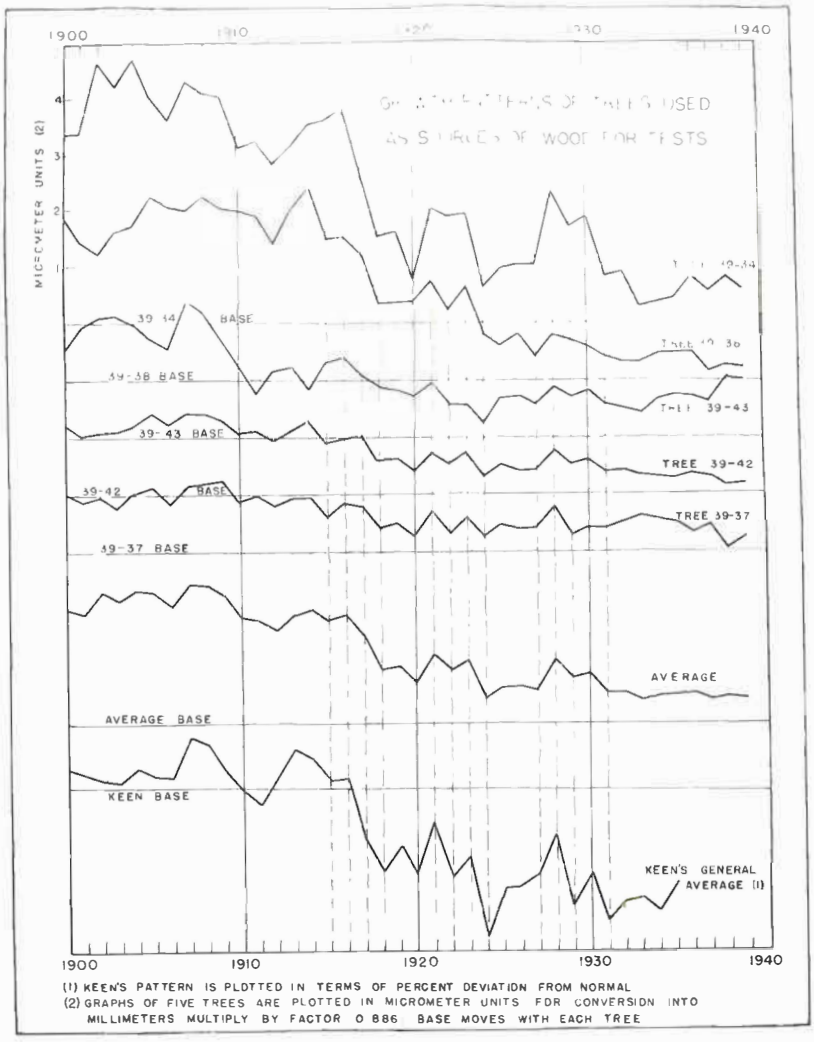
Tree 39-43 was an uninfested tree in an apparently vigorous and healthy condition. It was selected to provide a comparison of the conduction in wood from an uninfested tree with that in wood from infested trees. This tree was not felled, the wood for staining being cut from the tree at about breast height on the bole.

Tree 39-44 was a standing, infested tree which was used for one test of the stain in situ, the wood sample being chiseled out after application of the silver nitrate for developing and fixing of the staining solution. This one test gave no results, as the stain was not taken up. No other tests have been made since on standing trees.

Other Characteristics of Test Trees: The diameters and tree classifications of the trees used in these tests are shown in table II. Diameters at the stump ranged from 1.3 to 2.1 feet for the trees that were felled. Tree 39-43, which still stands, was measured at breast height. The physiological age ranged from immature to mature. The crown positions ranged from dominant through codiminant to suppressed.

PREPARATION OF SAMPLES

Following inspection of the growth sequence in cores and examination for flathead infestation, the selected trees were felled and cut into logs which were small enough to be transported to the field laboratory at Hackamore. At the same time cross sections, or wafers, were cut from the logs for later analysis of growth sequences.



(1) KEEN'S PATTERN IS PLOTTED IN TERMS OF PERCENT DEVIATION FROM NORMAL
(2) GRAPHS OF FIVE TREES ARE PLOTTED IN MICROMETER UNITS FOR CONVERSION INTO MILLIMETERS MULTIPLY BY FACTOR 0 886 BASE MOVES WITH EACH TREE

TEXT FIG 1

TABLE 2. NUMBERS OF SAMPLES USED IN ANALYSIS OF RESULTS.

Tree No.	Diameter at Stump	Classification Keen	Classification Dunning	Controls No. Used for Analysis.	Controls Total No. Stained.	Scarred Samples No. Used for Analysis.	Scarred Samples Total No. Stained.	Total No. Used for Analysis.	Grand Total No. Stained.
39-34	1.3 ft.	2B	1	19	19	70	70	89	89
39-37	1.5 ft.	3D	7	14	14	23	46	37	60
39-38	1.4 ft.	3B	3	14	14	29	46	43	60
39-42	2.1 ft.	3B	4	3	3	9	15	12	18
39-43	1.8 ft*	3B	3	3	18	-	-	3	18
Total 5				53	68	131	177	184	245

* At Breast Height.

At the field laboratory the cambium and scarred sapwood was exposed by carefully removing the bark and phloem from portions of the logs. The sapwood was kept wet during the interval necessary for the removal of bark and phloem as well as during all later handling in the preparation of the samples.

On the exposed sapwood, scars were selected and the dimensions of each sample were marked off on the wood. Blocks of wood carrying the scars were then chiseled from the logs. The samples were cut from these blocks, trimmed to a length of 7.7 cm and .8 cm square, the ends being cut cleanly across with a razor to provide unobstructed openings in the cut tracheids. Although this was not done under water, each sample was kept thoroughly wet during the operation. The corners at one end of the sample were rounded to allow close application of the walls of the rubber tubing to the surface of the sample when the connection between the two was made.

KINDS OF SAMPLES

A total of ~~five~~ two hundred forty-five samples from the five trees were used in these tests. Of these sixty-eight were unscarred samples or controls, and one hundred seventy-seven contained portions of one or more scars. The control samples serve as a basis for comparison of the behavior of solutions in unscarred wood with the behavior in the scarred samples. Because of great differences in factors affecting conduction in different trees, controls were taken from unscarred wood in the same infested tree. Because of possible variations in conduction on different sides of the same tree or at different heights on the bole, the control samples were, in addition, taken from the same sides and heights. They were taken from positions as closely adjacent as possible to the scarred samples with which they were to be compared. Plate 11 illustrates a control sample, the conduction pattern of which may be compared to those in adjacent scarred samples which were treated in a similar manner.

The types of flathead injury selected for testing were those which had caused scarring in the outer layers of the xylem. These were galleries, pitch blisters and pitch pockets. In most instances samples were taken from all sides of the trees. With the exception of samples from tree 39-43, which were taken from about breast height, the wood samples came from the upper third or quarter of the bole length.

METHODS OF STORING SAMPLES

Because securing of the logs and the removal and preparation of large numbers of samples took considerable time, the samples and wood blocks were stored in ice-chilled water until all samples were ready for staining. In the absence of suitable facilities, this method was used in an attempt to prevent changes by holding the wood at a temperature below physiological zero.

Samples were tested immediately after cutting and after they had been stored in ice-chilled water for periods of 24 and 52 hours. No visible significant changes in the conduction pattern could be noted. Another comparison was made between samples stored for forty-eight and seventy-two hours but no changes in the pattern could be found. In plate 16 are shown samples from the same side of the same tree treated at 6, 24, and 52 hours after removal from the tree.

Table 1 summarizes the number and conditions of trees used, the amount of infestation, the numbers of samples tested, the numbers of control and scarred samples, and the direction of the stain application.

BASIS FOR RESULTS

As a basis for the study of results, the samples from trees 39-34, 39-37, 39-38, 39-42, and 39-43 were used. Of the two hundred forty-five samples that were tested from these five trees, one hundred eighty-four were selected for microscopic examination. All the succeeding discussion is based on the analysis of these one hundred eighty-four samples. Table 2 summarizes, by trees, the number of control and scarred samples that were tested, and the number which forms the basis for this report.

Since there were fewer control samples, all were used in order that there would be a sufficient number for analysis of the characteristics of their staining behavior. Of the scarred samples, all from tree 39-34 were studied in detail, and a random selection of one-half or more of the scarred samples from the other trees made up the balance of the scarred series. As all samples of 39-43 were alike in staining reactions, only three were selected to be representative of that tree.

BASIS FOR ANALYSIS AND INTERPRETATION

In order to interpret the results, it was necessary to find some way of converting effects of staining that were apparent upon visual examination of the samples into some quantitative expression that would allow analysis and comparison. The evidence to be analyzed consisted of a pattern of stained wood exposed on the split surfaces of the samples. In making analysis of the pattern, the absence of precipitated silver in the annual rings of the samples was considered to indicate that the silver nitrate had been prevented from reaching the unstained portions of the rings, and that accordingly these rings were not conducting (within the time limit allowed for injection). A second possibility of faulty technique was not eliminated, but it was considered as being negligible because of the similarity of conduction patterns in samples from the adjacent wood.

Attempts to express the amount of staining on the basis of area or on the number of stained cells seemed unsatisfactory. After consideration of several possibilities the annual ring was chosen as the unit for expression of results. Counts were made of the number of annual rings per sample that had been fully stained, or were fully conductive in the period of time allowed for injection. These counts were then summed or otherwise ordered as a basis for computation and analysis of results. Text fig. 3, a: b.

The blocking effects of scars was tabulated in a similar fashion. In addition to counts of rings blocked per scar gradations of blocking were recognized. For that purpose categories of complete, partial, local. and no blocking were recognized. Local blocking was given no numerical value, as it represented only an interruption of stain in the cells near the scar. Partial blocking, which represented a considerable reduction in the amount of the stain passing the scar, was rated at 0.5 numerically. Full blocking consisted of stoppage of the stain at the scar, with the annual layer beyond the scar free of stain. It was given a value of 1.0. Such methods of working up data of course allow only general comparisons to be made. When differences are large and occur consistently, however, it may reasonably be believed that the numerical values are indicative and significant of differences between groups of samples. Text figure 3, b.

SIGNIFICANCE OF RESULTS

The significance of the results, as will be seen, lies in their suggestive nature. It is not possible to know, on present information, whether the results of the study are actually applicable to conditions in a living tree. However, a consideration of the results in the light of the physical and anatomical structures of the wood, and of the histological character of the scars themselves, suggests that the effects registered in the stained samples may well be indicative of the conditions obtaining in the scarred wood layers in the standing tree. The behavior of the scars in the samples, taken in conjunction with the behavior of copper sulfate in standing trees, provides evidence that may be helpful in providing for a better understanding of the biological relationships and importance of Melanophila californica Van Dyke in its host, ponderosa pine.

RESULTS

Briefly the results of this study, which includes the injection and careful visual appraisal of conduction patterns in two hundred forty-five samples and the microscopic examination of one hundred eighty-four samples may be summarized in the following nine points:

I. AN OUTER ZONE OF HIGHLY CONDUCTIVE TISSUE, INCLUDING FROM THREE TO MANY ANNUAL LAYERS IN DIFFERENT TREES, WAS FOUND TO OCCUR IN ALL TEST TREES.

II. THERE WAS A MARKED DIFFERENCE IN THE MOVEMENT OF STAIN THROUGH THE SCARS AND SCARRED SAMPLES AS COMPARED TO THE CONTROL SAMPLES.

III. BLOCKING OF STAIN MOVEMENT WAS GREATEST IN THE ANNUAL LAYERS OF THOSE YEARS IN WHICH THE FLATHEAD SCARS OCCURRED MORE FREQUENTLY.

IV. IN SAMPLES FROM THREE TREES NO EVIDENCE WAS FOUND THAT THE BLOCKING EFFECTS OF SCARS WERE COMPENSATED FOR BY AN INCREASE IN THE NUMBER OF CONDUCTIVE ANNUAL LAYERS INTERIOR TO THE SCARS.

V. THE CONDUCTIVE PROPERTIES OF NORMAL WOOD PRODUCED PERIPHERAL TO SCARS ARE NOT VISIBLY AFFECTED BY THOSE SCARS.

VI. BLOCKING BY SCARS RANGES FROM NO VISIBLE BLOCKING TO BLOCKING INVOLVING AS MANY AS SEVEN ANNUAL LAYERS.

VII. THERE IS A CUMULATIVE BLOCKING EFFECT WITH AN INCREASE IN NUMBER OF SCARS PER SAMPLE - THE GREATER THE NUMBER OF SCARS, THE GREATER THE NUMBER OF RINGS THAT ARE BLOCKED.

VIII. THE BLOCKING EFFECTS OF SCARS SEEM TO BE PHYSICAL IN NATURE.

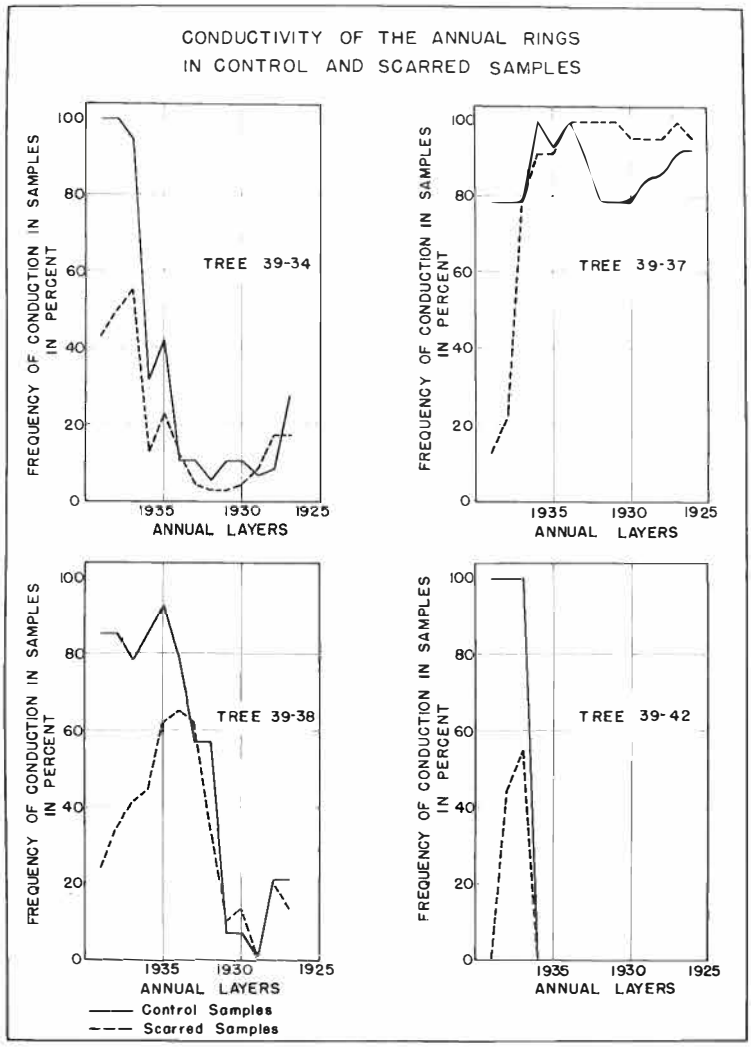
IX. THE PATTERNS OF CONDUCTION IN SCARRED SAMPLES SEEM TO DEMONSTRATE THAT A REAL BLOCKING IS CAUSED BY SCARS UPON LIQUIDS WHICH ARE DYNAMICALLY FLOWING THROUGH THE WOOD SAMPLES.

DISCUSSION OF RESULTS

I. A band of highly conductive tissue, including from three to many annual layers in different trees, was found to occur in all trees. (Refer to tables 3 and 5, plate 10, figures 1, 2, 3, 4, 5, and text figure 2.

(a) Only five control samples, three from tree 39-37 and two from tree 39-38 showed an incomplete filling in of the outer two or three layers. The general pattern for samples of each of the trees is shown in plate 10, figures 1, 2, 3, 4. and 5, and is indicated in tables 3 and 4, and in graphs of text figure 2.

(b) The width of the conductive zone varied from the very narrow zone of three annual layers in tree 39-42 to a zone extending across the entire thickness of the sample as in most of the samples from tree 39-37 and all of the samples from the uninfested tree 39-43. The pattern of conduction in the samples of these last two trees is regarded as indicating that the breadth of the conductive wood merely was broader than the limits of the samples, rather than indicating an essentially different type of conduction.


CONDUCTIVITY OF THE ANNUAL RINGS
IN CONTROL AND SCARRED SAMPLES
FREQUENCY OF CONDUCTION IN SAMPLES IN PERCENT
100
80
60
40
20
0
TREE 39-34
1935
1930
1925
ANNUAL LAYERS
TREE 39-37
TREE 39-38
TREE 39-42
Control Samples
Scarred Samples

TEXT FIG. 2

(c) A variation in the average conductivity of the samples accompanies variations in the width of the conductive zone of wood This is shown by table 9. The relation of rings conducting to total rings in the samples varied from 17.7 percent in tree 39-42 to 100 percent in tree 39-43

The significance of such variation is considerable if viewed in the light of possible effects of obstruction to conduction in the annual layers of samples from trees 39-34, 39-38, and 39-42 In the samples from these trees the highly conductive zone is confined to the outermost three to seven layers It would seem probable that obstructions to conduction in these layers would seriously decrease the possible amount of conduction unless compensation, in some form, took place. In the samples from tree 39-37, the wood through the entire thickness of the samples was highly conductive and obstruction in the outermost two or three layers would be expected to affect only a small percentage of the total conductive wood, with a consequently slight effect upon the conductivity of the samples.

The above is indicated by the figures for percentage reduction of conductivity in scarred wood samples as compared to that in control samples which are given in table 9. Those figures might be interpreted as indicating that the relative effects of obstruction on conductivity was greatest in the samples from tree 39-42, which had a narrow zone of conductive wood, and least in the samples from tree 39-37, which had the widest band of conductive wood of any of the scarred samples

TABLE 3.
FREQUENCY OF FULL CONDUCTION OF ANNUAL RINGS IN CONTROL SAMPLES

Tree No.	Total No. Samples	Number of Samples with these Annual Layers Fully Conductive '39	'38	'37	'36	'35	'34	'33	'32	'31	'30	'29	'28	'27	'26	'25	'24
39-34	19	19	19	18	6	8	2	2	1	2	2	1.2	1.5				
39-37	14	11	11	11	14	13	14	13	11	11	11	12	12	13	13	13	
39-38	14	12	12	11	12	13	11	8	8	1	1	-	3	3			
39-42	3	3	3	3	-	-	-	-	-	-	-	-					
39-43	3 (out of 18)	3	3	3	3	3	3	3	3	3	3						
Total	53	48	48	46	35	37	30	26	23	17	17	-	-	-	-	-	

II. There was a marked difference in the movement of stain through the scars and scarred samples as compared to the control samples. Tables 3, 4, 5, 9, text figure 2, plates 11-16, and text figure 3, a and b.

(a) An examination of plates 11, 12, 13, 14, 15, 16, and text figure 3, a and b, shows that there was a blocking out of layers and a reduction in the amount of wood that was stained in samples with scars as compared to the amount of staining and the pattern of staining in control samples.

(b) When one counts the number of times each of the annual layers are conductive in the controls and in the scarred samples (tables 3 and 4) and expresses the number in terms of percent (table 5) the difference and reduction in conductivity of the scarred samples compared with the conductivity of the control samples is numerically evident. Plotting the information graphically in text figure 2 demonstrates that there is a distinct difference between the conductivity pattern of the control samples and the conductivity of the scarred samples.

(c) If the average percentage of annual rings conducting in the scarred samples is computed, and compared with the average percentage of conducting annual rings in the control samples (table 9) a difference and definite reduction in average percentage of conductivity for the scarred samples is seen. The reduction is 37.3 percent of the conductivity of the control samples.

TABLE 5.

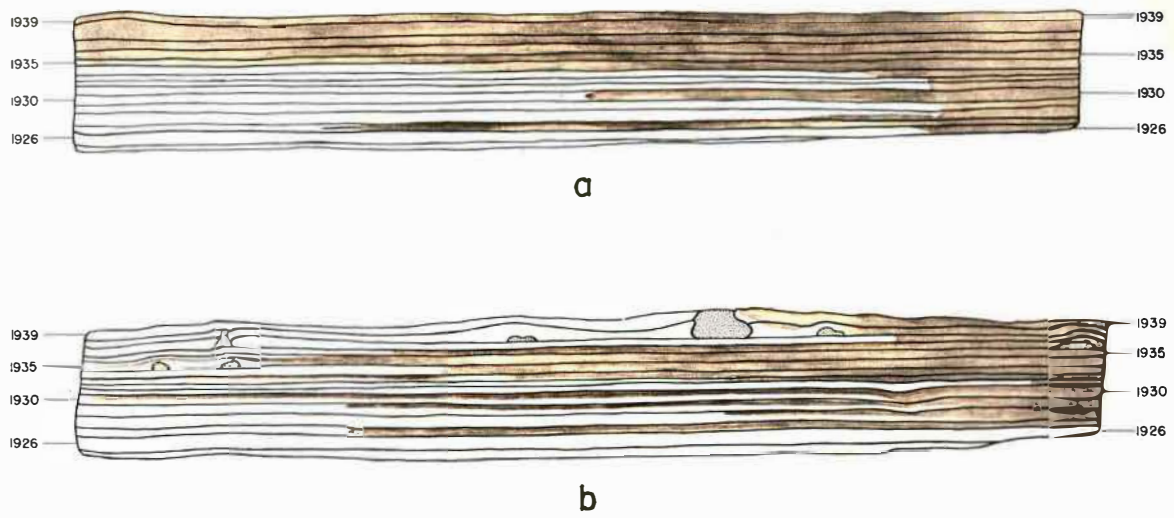
FREQUENCY OF FULL CONDUCTION OF ANNUAL RINGS IN SCARRED SAMPLES

Tree No.	Total No. Samples	Number of Samples with these Annual Layers Fully Conductive '39	'38	'37	'36	'35	'34	'33	'32	'31	'30	'29	'28	'27	'26	'25	'24
39-34	70	30	35	39	9	16	9	3	2	2	3						
39-37	23	3	5	18	21	21	23	23	23	23	22	22	22	23	22		
39-38	29	7	10	12	13	18	19	18	10	3	4	-	6	4			
39-42	9	0	4	5	-	-	-	-	-	-	-	-	-	-			
39-43	None	Uninfested check tree.															
Total	131	40	54	74	43	55	51	44	45	28	29	-	-	-			

TABLE 5. PERCENTAGES OF ANNUAL RINGS THAT ARE CONDUCTIVE IN SCARRED AND CONTROL SAMPLES.

Tree No.	Kind of Samples	Total No. Samples	Percent of Samples with these Annual Rings Fully Conductive														
			'39	'38	'37	'36	'35	'34	'33	'32	'31	'30	'29	'28	'27	'26	'25
39-34	Controls	19	100	100	94.7	31.6	42.1	10.5	10.5	5.3	10.5	10.5	6.7	8.3	27.3		
"	Scarred	70	42.9	50.0	55.7	12.9	22.9	12.9	4.3	2.9	2.9	4.3	8.6	17.5	17.2		
"	% Reduction in Scarre		57.1	50.0	41.2	59.2	45.6	-	59.0	45.3	72.4	59.0	-	-	-		
39-37	Controls	14	78.6	78.6	78.6	100	92.8	100	92.8	78.6	78.6	78.6	85.7	85.7	92.8	92.8	
"	Scarred	23	13.0	21.7	78.3	91.3	91.3	100	100	100	100	95.7	95.7	95.7	100	95.7	
"	% Reduction in Scarred		83.5	72.4	0.4	8.7	1.6	-	-	-	-	-	-	-	-	-	
39-38	Controls	14	85.7	85.7	78.6	85.7	92.9	78.6	57.1	57.1	7.1	7.1	-	21.4	21.4	-	
"	Scarred	29	24.1	34.5	41.4	44.8	62.1	65.5	62.1	34.5	10.3	13.8	-	20.7	13.8	-	
"	% Reduction in Scarred		39.1	59.7	47.3	47.7	33.2	16.7	-	-	-	-	-	-	-	-	
39-42	Controls	3	100	100	100	-	-	-	-	-	-	-	-	-	-	-	
"	Scarred	9	00.0	44.4	55.6	-	-	-	-	-	-	-	-	-	-	-	
"	% Reduction in Scarred		100	55.6	44.4	-	-	-	-	-	-		-	-	-	-	
Average	Controls		91.1	91.1	88.0	54.3	57.0	47.3	40.1	35.3	24.1	24.1	23.1	-	-	-	
"	Scarred		20.0	37.7	57.8	37.3	44.1	44.6	41.6	34.4	28.3	28.5	16.8	-	-	-	
"	% Reduction in Scarred		69.9	59.4	33.3	31.3	22.6	5.8	-	-	-	-	-	-	-	-	

DIAGRAMMATIC SKETCH OF THE CONDUCTION PATTERN
IN THE ANNUAL RINGS OF A CONTROL SAMPLE AND OF A SCARRED SAMPLE



TEXT FIGURE 3.

Text figure 3 presents diagrammatic sketches of the conduction patterns of the annual rings of two samples from tree 39-38. These samples are figured in plate 15, figures e and f. The upper figure is a control sample used for comparison with the scarred sample of the lower figure. The stained wood is represented by the shaded areas, the stain movement in the samples being from right to left. The annual layers are delimited by the lines, their dates of formation being indicated at the ends of the samples. In the scarred sample the pitchy parenchyma scars are represented in stipple. Blocking took place on the sides of the scars away from the point of injection of the stain.

These sketches, which are only approximate and diagrammatic, supplement the photographic plates by showing the relations of the conduction patterns and patterns of blocking to the annual rings and scars. Limitations of magnification and of definition of stained areas and scars in the photographic plates prevent ready analysis of the patterns of conduction in terms of annual rings. By examining the pattern of conduction of the samples microscopically and analysing it on the basis of annual rings and scars, and with the concept of the pattern as being representative of the lines of flow of the solution dynamically during the interval of injection in the wood, it was possible to obtain data that expressed the general relations of scars to blocking, and to compare in a general way the differences in conductivity in the controls and scarred samples. Magnifications: x 1.66 diameters; photograph 12349H by J. M. Miller.

III. Blocking of stain movement was greatest in the annual layers of those years in which the flathead scars occurred more frequently. Tables 5, 6, 7, 8, 9, 10, plates 11-16, text figure 3, a and b.

(a) Visual inspection of the patterns of the scarred samples and comparison with control samples (plates 11-16. text figure 3, a and b) shows that when scars are present in areas which are conductive in controls, there is a reduction in the amount of wood that is stained. The reduction in conductivity of stain, in other words, occurs in those years that have scars, and this reduction is definitely associated with presence of these scars.

(b) A comparison of the distribution of the scars by years with the distribution of the years having a great reduction of conductivity (tables 5, 6, 7) indicates a definite relationship between presence of many scars and a great reduction in conductivity. This relationship, however, is not perfect. It is affected by the general conductivity of the year in which scars occur, the overlapping effects of scars which may influence other years than the one in which they occur, and the interference between scars which lie in the same annual layer. The first scar may block out the stain, leaving the others apparently ineffective.

(c) Table 8 shows the correlation of periods of years embracing a high percentage of scars with the average reduction in conductivity for these same years. Table 10 shows the average percent reduction for each of the trees for the years which have scars. There is a good correspondence between trees in the percentage reduction of conductivity for the scar-bearing years. In tree 39-37 in which the reduction of conductivity of the whole scarred samples was only 5.3 percent (table 9), the average reduction of conductivity for the years with scars was 39.1 percent, showing that the scars had a considerable effect in the years they affect.

From discussion under sections III and IV it seems apparent that (1) scarred wood was much less conductive of the stain solution, and (2) this reduction in conductivity was due to blocking of the stain by scars from those annual layers bearing the scars.

TABLE 6. DISTRIBUTION OF SCARS BY ANNUAL RINGS

Tree No.	Total No. of Scars	Number of Scars in These Annual Layers												
		'39	'38	'37	'36	'35	'34	'33	'32	'31	'30	'29	'28	'27
39-34	162	15	21	29	34	33	7	12	7	-	2	1	1	-
39-37	26	9	14	2	1	-	-	-	-	-	-	-	-	-
39-38	67	2	21	15	11	6	1	9	-	-	-	-	1	1
39-42	20	12	7	-	1	-	-	-	-	-	-	-	-	-
Total	275	38	63	46	47	39	8	21	7	-	2	1	2	1

TABLE 7. PERCENTAGE DISTRIBUTION OF SCARS BY ANNUAL LAYERS

Total No.	Total No. of Scars	Percent of Total Number of Scars in these Annual Layers '39	'38	'37	'36	'35	'34	'33	'32	'31	'30	'29	'28	'27
39-34	162	9.3	13.0	17.9	21.0	20.4	4.3	7.4	4.3	-	1.2	.6	.6	-
39-37	26	34.6	53.8	7.7	3.8	-	-	-	-	-	-	-	-	-
39-38	67	3.0	31.3	22.4	16.4	9.0	1.5	13.4	-	-	-	-	1.5	1.5
39-42	20	60.0	35.0	-	5.0	-	-	-	-	-	-	-	-	-
Aver.		26.7	33.3	12.0	11.6	7.4	1.4	5.2	1.1	-	.3	.2	.5	.4

TABLE 8. GENERAL CORRELATION BETWEEN PERIODS OF HIGH INFESTATION AND REDUCTION IN CONDUCTIVITY IN THE WOOD FOR THESE SAME PERIODS.

Tree No.	Period in Years	Percent of Scars in these Years	Aver. % Reduction in Conductivity
39-34	Last 5	81.6	47.8
39-37	Last 2	88.4	78.0
39-38	Last 5	82.1	45.4
39-42	Last 2	95.0	77.8

IV. In the samples from three trees, no evidence was found that the blocking effects of scars were compensated for by an increase in the number of conductive annual layers interior to the scars. Tables 9, 10, 11.

(a) In the samples from the three trees 39-34, 39-38, and 39-42, the limits of the conductive zone lay within the sample. It was possible to consider, therefore, whether there was a compensation for blocking by an increase in the number of conductive annual rings interior to the scars.

A comparison between the average percentage reduction of conduction for the whole scarred samples, and the average percentage reduction for the scarred years only, as shown in table 11, shows close correspondence between figures. This is interpreted as demonstrating that no apparent compensation for blocking has taken place in the scarred samples. If such compensation did occur of the form suggested, there should be no difference between the conductivity of the scarred samples as a whole, and the conductivity of the control samples as a whole. But the information, necessarily, is limited to the thickness of the sample.

(b) With respect to the samples of tree 39-37, it is not possible to determine whether compensation occurs. The inner limits of the conductive zone lie beyond the limits of the sample. As seen in table 11, the blocking in the scarred years is largely offset by the conductivity of the samples as a whole. The results, in the case of the samples of Tree 39-37, do not necessarily controvert the conclusion drawn above.

TABLE 9. RELATIVE CONDUCTIVITY OF CONTROLS AND SCARRED WOOD SAMPLES

For the Whole Samples

Tree No.	Kind of Samples	Total No. Samples	Total No. Rings	Total No. Cond. Rings	% of Rings Cond. (1)	% Contr. Minus % Scarred (2)	% Reduct. in Scarred (3)
39-34	Control	19	245	84	34.3	15.2	
"	Scarred	70	883	169	19.1		44.2
39-37	Control	14	252	218	86.5	4.6	
	Scarred	23	404	331	81.9		5.3
39-38	Control	14	230	95	41.3	13.9	
"	Scarred	29	452	124	27.4		33.6
39-42	Control	3	51	9	17.7	11.7	
	Scarred	9	151	9	6.0		66.2
Average	Controls				44.9	11.3	
"	Scarred				33.6		37.3

(1) Percent of rings conducting was computed by dividing the total number of conducting rings in all samples by the total number of rings in all samples.

(2) Percent of controls minus percent of scarred is the difference between the percent of rings conductive in controls and the percent of rings conductive in scarred samples. It is used in calculating the percent reduction in scarred samples.

(3) Percent reduction in scarred samples is computed by dividing the percent of rings conducting in the control samples into the difference between the percents of conductivity of controls and scarred samples.

TABLE 10. RELATIVE CONDUCTIVITY OF CONTROL AND SCARRED SAMPLES FOR SCARRED YEARS ONLY

Tree No.	Kind of Samples	Total No. Samples	Total No. Rings	Total No. Rings Cond.	Percent of Rings Cond.(1)	Percent Contr. Minus % Scarred(2)	% Reduct. in Scarred(3)	No. Yrs. Scarred
39-34	Control	19	209	79	37.8	16.8	44.4	11
	Scarred	70	770	162	21.0			
39-37	Control	14	56	47	83.9	32.8	39.1	4
	Scarred	23	92	47	51.1			
39-38	Control	14	126	85	67.8	26.8	39.5	9
"	Scarred	29	261	107	41.0			
39-42	Control	3	9	9	100.0	66.7	66.7	3
"	Scarred	9	27	9	33.3			
Averages	Control				72.4	35.8	47.4	
	Scarred				36.6			

(1) Percent of rings conducting was computed by dividing the total number of conducting rings in all samples by the total number of rings in all samples.

(2) Percent of controls minus percent of scarred is the difference between the percent of rings conductive in scarred samples. It is used in calculating the percent reduction in scarred samples.

(3) Percent reduction in scarred samples is computed by dividing the percent of rings conducting in the control samples into the difference between the percents of conductivity of controls and scarred samples.

TABLE 11. COMPARISON OF RELATIVE CONDUCTIVITY OF SAMPLES FOR SCARRED YEARS ONLY WITH RELATIVE CONDUCTIVITY OF WHOLE SAMPLES

Tree No.	Kind of Samples	% Rings Cond. in Scarred Years	% Rings Cond. in Whole Sample	% Reduct. in Conduct. in Scarred Years	% Reduct. in Conduct in Whole Sample
39-34	Control	38.1	34.3		
"	Scarred	21.0	19.1	44.4	44.2
39-37	Control	83.9	86.5		
"	Scarred	51.1	81.9	39.1	5.3
39-38	Control	67.8	41.3		
"	Scarred	41.0	27.4	39.5	33.6
39-42	Control	100.0	17.7		
"	Scarred	33.3	6.0	66.7	66.2
Average	Control	72.5	44.9		
"	Scarred	36.6	33.6	47.4	37.3

V. The conductive properties of normal wood produced peripheral to scars are not visibly affected by the scars. Plate 11, figure 2.

(a) A number of cases in which undisturbed wood peripheral to scars carried stain readily through the length of the samples. An example is figured in plate 11, figure 2. This phenomenon is possible when the scar is deep in the wood, so that the scar tissue no longer reaches the surface.

VI. Blocking by scars ranges from no visible blocking to blocking involving as many as seven annual layers. Table 12, plate 12, figure 5.

(a) This result is to be expected. The amount of injury caused by incipients varies with the size and age of the incipient, and perhaps with the season of the year, the physiological condition of the tree, and the activity of the larva. Some injuries are not of sufficient size to cause any marked formation of pitch and scar tissue. However, 86.5 percent of all the scars had some effect, and in 60.4 percent of the cases tested, the scars blocked one or more annual layers. The average blocking effect of all scars was 1.1 annual layers per scar (table 13).

(b) As a corollary to the variation in effects of scars, it is also true that not all points along the length of a gallery have the same blocking effect. This was found by repeatedly splitting samples, and developing the pattern. The blocking varied with the character of the scar at each point of splitting.

(c) The appearance of blocking generally took place at the scar. The stain was able to enter the annual layer and move as far as the scar, but no farther. In a number of cases, however, the wood in the annual layer preceding the scar remained free of stain also. The phenomenon suggests the analogous results of trying to force water into a full pipe which has been capped at the other end.

Table 12 gives a rough summary of the variation in the amounts of blocking of scars for all scarred samples.

TABLE 12. NUMBER OF SCARS AND AMOUNT OF BLOCKING DISTRIBUTED BY YEARS

No. Rings Blocked	'39	'38	'37	'36	'35	'34	'33	'32	'31	'30	'29	'28	'27	Total	Percent
Local		3	4	3	3		2							15	6.8
0.5	8	5	12	2	10	1	2	1		1		1		43	19.4
1.0	13	21	4	16	8	2	2	1				1		68	30.6
2.0	5	15	7	3	2		3							35	15.8
3.0		4	7	2			2							15	6.8
4.0			1	6	2									9	4.1
5.0		1		1	1									3	1.4
6.0		1		2										3	1.4
7.0							1							1	.5
Total	26	50	35	35	26	3	12	2		1		2		192	
Percent	11.7	22.5	15.8	15.8	11.7	1.4	5.4	.9		.5		.9			86.5
Number No Blocking	6	6	7	3	2		5	1						30	13.5
Percent	2.7	2.7	3.2	1.4	.9		.5	.9							
2nd. Total	32	56	42	38	28	3	17	3		1		2		222	100.0
Ineffective Scars	6	7	4	9	11	5	4	4		1	1		1	53	
Grand Total	38	63	46	47	39	8	21	7		2	1	2	1	275	

TABLE 13. AVERAGE BLOCKING EFFECT OF ONE SCAR

Tree No.	Average No. Rings Blocked by One Scar
39-34	1.0
39-37	1.4
39-38	1.3
39-42	.8
Average	1.1

VII. There is a cumulative blocking effect with an increase in the number of scars per sample, the greater the number of scars present, the greater the number of rings blocked. Table 14, plates 11 and 12.

(a) A visual examination of samples with several scars shows that more scars tend to block out more rings. See plates 11 and 12. The increase is not proportional, nor does it always occur, for several factors affect the appearance of this result. Scars in the same layer may interfere with each other, - the first blocking the layer and rendering those that follow superflous. Large scars beyond which other scars are situated may block several rings. Very small scars may cause no appreciable blocking.

(b) The cumulative effect of several scars is quite apparent when the samples are grouped according to the number of scars. In preparing table 14, the samples were grouped by number of scars that were in or adjacent to the conductive zone. Each sample was then examined. The number of conducting rings preceding the first scar and the amount of blocking taking place after each scar was tabulated and the sums taken for all the groups. From these was computed the average amount of blocking taking place in samples with different numbers of scars. In table 14 is indicated the increase in the number of rings blocked per sample with the increase in number of scars per sample. In the higher categories, because of the few samples available with so many scars, the averages become less reliable.

The apparent cumulative blocking effects of scars as their number increases seems significant. The effect of hundreds of scars over a linear distance of thirty or forty feet might be very considerable in blocking or retarding the movement of liquids through the layers infested with them. Their total effect might be compared to the effects of many weeds in a small ditch, - by causing many interruptions and diversions in the movement of the liquids, materially reducing the rate of flow. In living pine trees, it is not unusual to find infestations amounting from hundreds to several thousands of these scars, with considerable deformation to the surface of the bole of the tree.

TABLE 14. RELATION OF AVERAGE NUMBER OF RINGS BLOCKED TO NUMBER OF SCARS PER SAMPLE

Tree No.	Number of Scars per Sample						
	1	2	3	4	5	6	7
39-34	1.2	2.2	2.9	3.6	4.1		
39-37	1.5	2.2					
39-38	1.7	2.6	4.2	4.4	5.0	5.3	5.3
39-42*	2.0*	1.7					
Average	1.3**	2.4	3.6	4.0	4.6	-	-

* Insufficient sample in first column - 2 samples only.

**This average is based upon a smaller number than the general average for all scars in table 13.

VIII. The blocking effects of scars seem to be physical in nature. Plate 15. After making the injections of samples of trees 39-34 and 39-37, all of which, except two, were injected from the morphologically lower ends of the samples, the samples of 39-38 were injected in reverse. No difference in blocking behavior between these "reversed" samples and the normally injected samples was apparent. In both cases, blocking took place on the side of the scar away from the end where the stain was applied. This seems to indicate that blocking by scars behaves as if it were due to physical obstruction of the annual layers. It seems to indicate, also, that the failure of stain to enter wood morphologically above the scars in normally injected samples was not due to a chemical lack of affinity or repelling action of the wood for the stain. There is little reason for believing that there are toxic reactions due to flathead injury which result in changes in the wood above the galleries and cause failure of these areas to stain. But the possibility of the larva having a toxic effect upon the host is not eliminated. See plate 15.

Because of the similarity in behavior of the "reversed" samples of tree 39-38 to the behavior of the normally injected samples, these "reversed" samples were handled along with the other samples in preparing the results.

IX. The pattern in scarred samples seems to demonstrate that scars effectively block liquids which are dynamically flowing through the wood. Plates 11 - 16, text figure 3, a and b.

(a) In the first tests that were made with aniline dyes to develop a good method for passing liquid through wood and studying the effects of scars, it was soon noted that there were differences between patterns of conduction produced by stain that was moving through the wood under force and the patterns of passive conduction produced by capillary action and by diffusion of stains in wood samples. This differences seemed important to the investigators. Two factors seemed to be involved, - one was the time interval, and the other the difference between dynamic flow and more or less static diffusion.

(b) In tests with aniline stains (plate 14) which were applied under pressure to scarred samples for a short time, and then the samples immediately cut open for observation, it was seen that blocking occurred behind scars. These annual layers that were blocked were not functioning actively in the transport of the stain longitudinally along the sample. When stain was applied for a long time, or when samples that had been stained for a short interval were allowed to stand for a number of minutes, lateral diffusion along medullary rays would occur, and the blocked layers would acquire the aniline stain. It seemed apparent, therefore, that the scars were causing chiefly blocking of longitudinal movements.

(c) In the dynamic longitudinal type of movement the transmission of a force along the conducting layers is necessary to make the flow of stain possible through the layers. The passive radial movement could be explained by the simple diffusibility of the stain. It seemed, therefore, that when annual layers beyond the scar failed to readily fill with and transmit the stain, the scars were preventing the transmission of the force along the scarred annual ring that was needed to make it a part of the system functioning in the active flow of stain through the sample. Thus, while the scar would not prevent the cross diffusion of liquid into the annual layers beyond the scar, it did significantly block out or render the annual layer unusable for at least the length of the sample as a part of the longitudinal conducting system because it acted as a barrier to the transmission of the force inducing the movement of liquid through the layer.

(d) The possible implications of this behavior discovered in these early tests were considered in the light of the tree. Water moves up a tree in a definite stream. When rapid transpiration is occurring, the amount of the stream would be important, and the time factor as well. Obstructions, therefore, which would tend to interrupt the direct transmission of the forces impelling water up the tree might either reduce the amount of water being transported by reducing the cross-sectional area through which these forces act, or perhaps cause the liquid to take a more circuitous route or to move at a faster rate, thereby affecting the forces responsible for the movement and the physiological phenomena causing these. This would mean that interruptions to conduction might affect the dynamic processes of the tree.

(e) With a consideration of the results of the early tests, and the implications of these for the trees, the pattern of conductivity as it existed during the dynamic movement of stain through the samples seemed of first importance. Aniline stains were an unsatisfactory medium. The lateral diffusion which took place subsequent to injection obscured the initial pattern, and no evidence could be preserved for later study. To this end a silver nitrate stain was chosen, as the silver is readily precipitated out of solution, and it was possible by using it, to preserve the patterns of conductivity along planes split through the samples immediately after injection. The time interval was shortened until it was just sufficient to allow the stain to move through the unscarred conductive areas, which made possible determination of those areas which were not actively transmitting the liquid. With the treatment of a large number of samples by this method, a definite blocking effect of scars upon actively moving staining solutions in wood seems to have been demonstrated.

The significance of these results, as stated earlier in the report lies in their implications of the effects of flathead injury in the living tree. Whether the results of the tests provide a factual basis for interpretation of the effects of flathead scars upon the tree is a question that cannot be answered. The apparent blocking of dynamic liquid movements in wood by the scar and the cumulative effects of these scars as their numbers

increase offer a possible mechanism for interference with the water relations and the physiology of the tree. The results of the tests of copper sulphate injection of living trees may possibly be further evidence on a larger scale for the effects of flathead scars on the trees.

In carrying out this problem, many difficulties were encountered. Methods used to overcome these were selected on the basis of their consistency with the objective of the study and the information that is pertinent to it. Results which seem suggestive of definite blocking effects on the tree have been regularly associated with the individual scars in sapwood. However, there are possibly other more important effects that may be related to the injuries and scars produced in the phloem. As indicated by some physiologists (Curtis, 7), injuries to the phloem may be far more significant in their effect upon the tree than injuries to the xylem. However, the difficulties attendant upon any attempts to make a study of injuries to the phloem and the physiological effects of these on the tree are of such a nature and magnitude as to make almost impossible the securing of satisfactory results. Leaving these problems unanswered, it is believed that the results of the tests of sapwood injury when considered with other evidence may be helpful in a final understanding of the relation of Melanophila californica Van Dyke to the health of the ponderosa pines.

SUMMARY OF REPORT

1. A study was made of the effects of wood scars caused by the larvae of the California Pine Flathead, Melanophila californica Van Dyke, in the sapwood of living ponderosa pine trees upon the conductivity of the wood.

2. Evidence was obtained for the study by removing samples of wood of uniform size from freshly felled trees and injecting the samples with a silver nitrate stain. By splitting the samples immediately after injection and precipitation of the silver from solution with a photographic developer, the conduction patterns of the samples were preserved and available for further study and analysis.

3. Four trees infested with flathead larvae, and one uninfested tree were used as sources of fresh wood. All trees had full growth complements.

4. Samples from infested trees were of two kinds, scarred samples, and control samples, the control samples being free of flathead injury and taken from wood adjacent to the scarred samples for which they acted as controls.

5. Two hundred forty-five samples were tested with silver stain. Of these one hundred eighty-four were selected for intensive microscopic analysis.

6. Flathead scars seem to have a definite blocking effect upon solutions moving ~~dynamically~~ through scarred wood. This effect results in a reduction in the amount of wood available for rapid transport of the staining solution longitudinally through the wood.

7. If the results of the study are applicable to living trees, the flathead scars may exercise a definite influence upon the tree by affecting the water relations of the tree.

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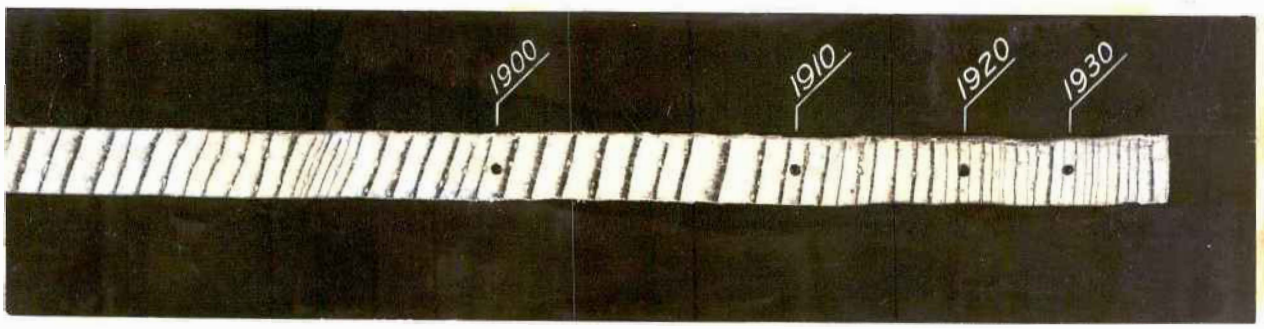

Plate 1.

CORE FROM HEALTHY TREE WITH COMPLETE GROWTH RECORD

A full complement of growth rings is shown by this core taken at breast height from the south side of the vigorous, uninfested tree 39-43. The growth pattern of this tree agrees closely with the general pattern for growth of pines of the Modoc region, making it possible to cross-date the rings with Keen's master sequence. In this way the completeness of the growth complement was established. Black spots have been placed on the annual layers of the decade years 1900, 1910, 1920, and 1930 to facilitate identification of rings. This practice is followed with the cross-sections of the other four trees. 39-34, 39-37, 39-38, 39-42.

Magnification: x 2.1 diameters; photograph 11249X by J. E. Patterson.

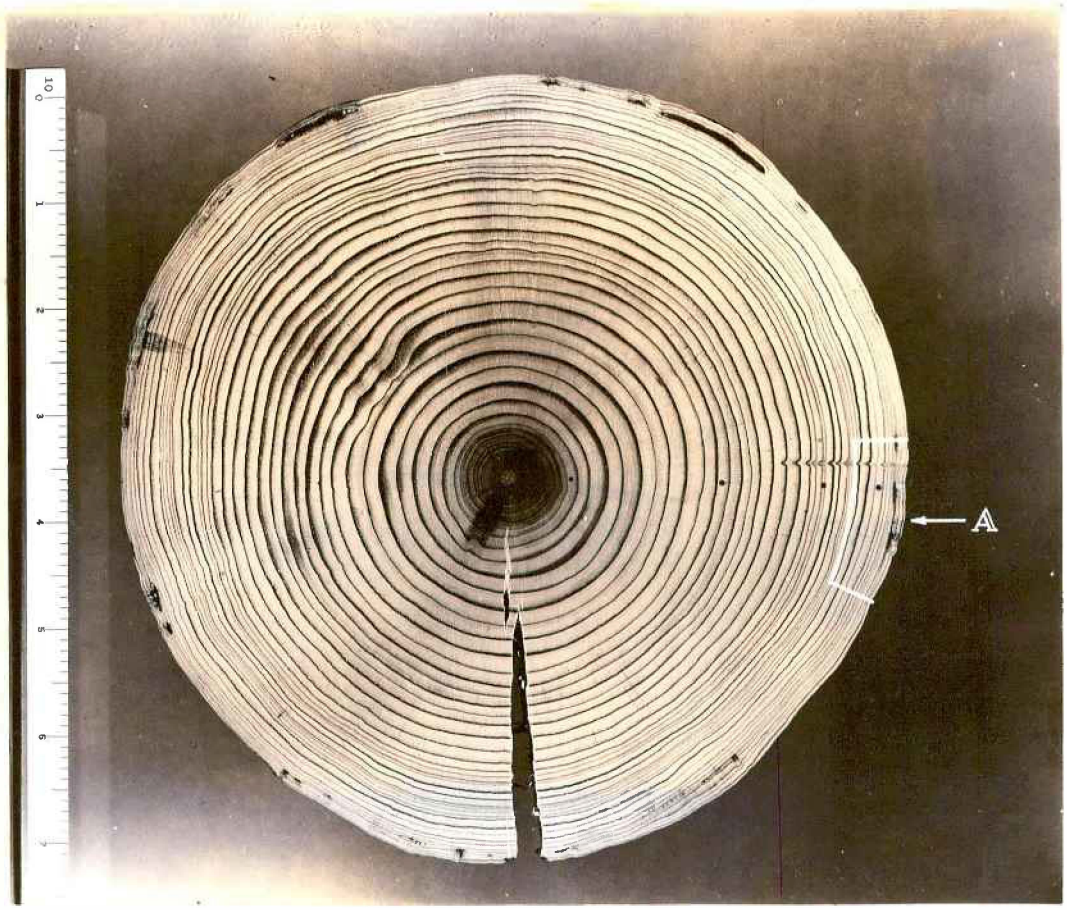

Plate 2.

A CROSS-SECTION AT TWENTY FEET OF THE STEM OF TREE 39-34
SAMPLES FOR INJECTION WERE TAKEN FROM ADJACENT PORTIONS
OF THE BOLE OF THIS TREE.

This shows a complete growth complement of annual layers since the year of 1900. The diameter of the section is indicated by comparing it with the inch scale of the rule to the left. Flathead incipient scars are visible in the peripheral layers of the cross-section.

At no point in the periphery of the section were rings incomplete. The growth pattern was readily cross-dated with Keen's master sequence. To show the narrow rings of recent years more clearly, the area within the section A is figured in enlarged detail in Plate 3.

Magnification: x .561 diameters; photograph 11249A by J. E. Patterson.

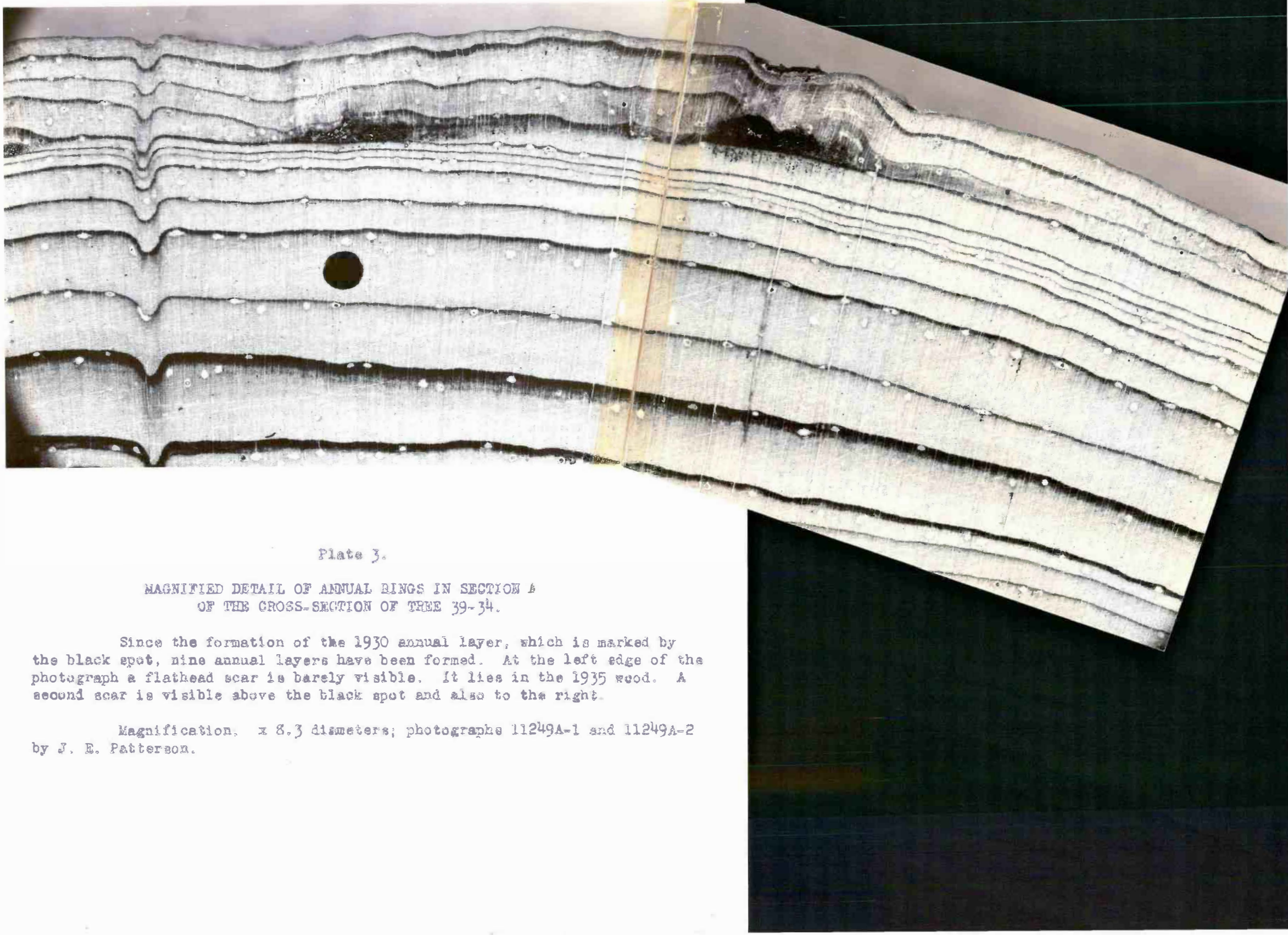

Plate 3.

MAGNIFIED DETAIL OF ANNUAL RINGS IN SECTION B
OF THE CROSS-SECTION OF TREE 39-34.

Since the formation of the 1930 annual layer, which is marked by the black spot, nine annual layers have been formed. At the left edge of the photograph a flathead scar is barely visible. It lies in the 1935 wood. A second scar is visible above the black spot and also to the right.

Magnification, x 8.3 diameters; photographs 11249A-1 and 11249A-2 by J. E. Patterson.

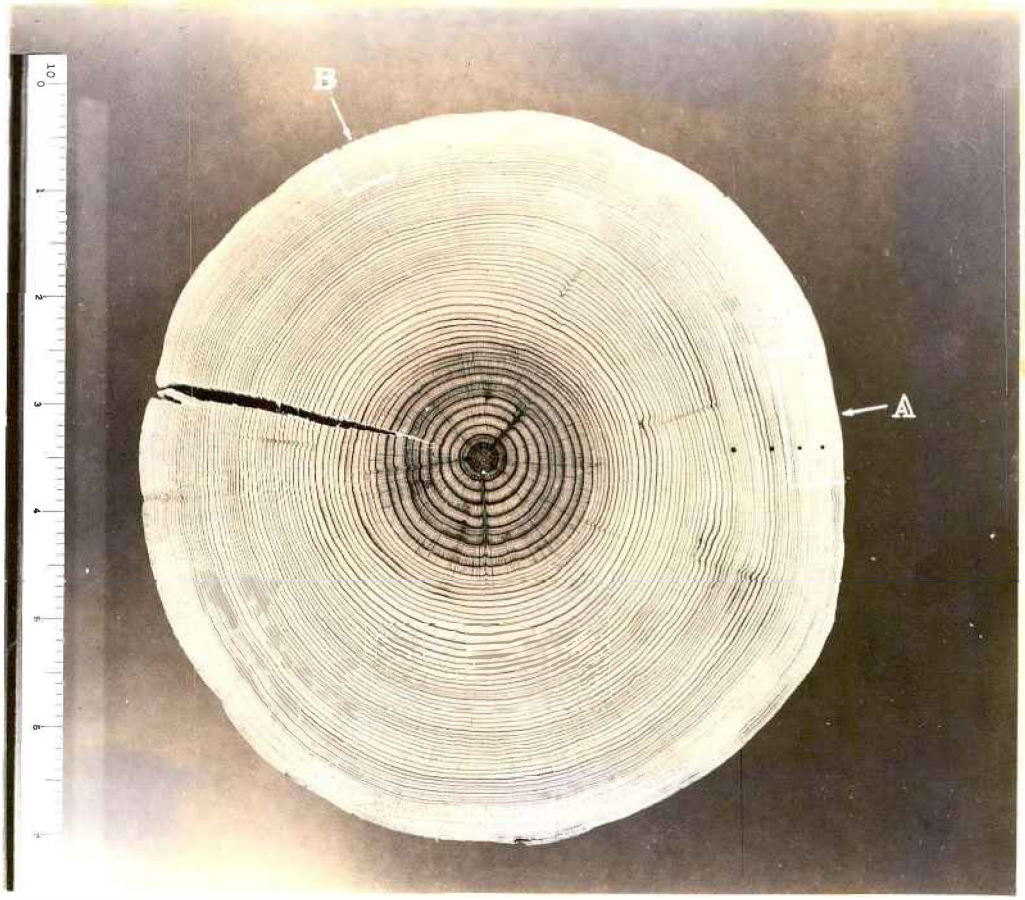

Plate 4.

CROSS-SECTION TAKEN AT FIFTY FEET OF THE STEM OF TREE 39-37.
SAMPLES FOR SUBSEQUENT TREATMENT WERE TAKEN
FROM ADJACENT PORTIONS OF THIS BOLE.

No rings are missing completely in the forty-year period since 1900. The 1938 ring is narrow and incomplete at one point of the periphery of the section. The narrow rings of recent years are illustrated in plates 5A and 5B which were taken from section A and B of the cross-section. Flathead scars are small, recent in formation and not readily visible in this cross-section.

Tree 39-37 is a mature tree with placid growth, but the growth pattern of the past forty years was readily cross-dated with the master growth pattern of the trees of this region.

Magnification: x .563 diameters; photograph 11249B by J. E. Patterson.

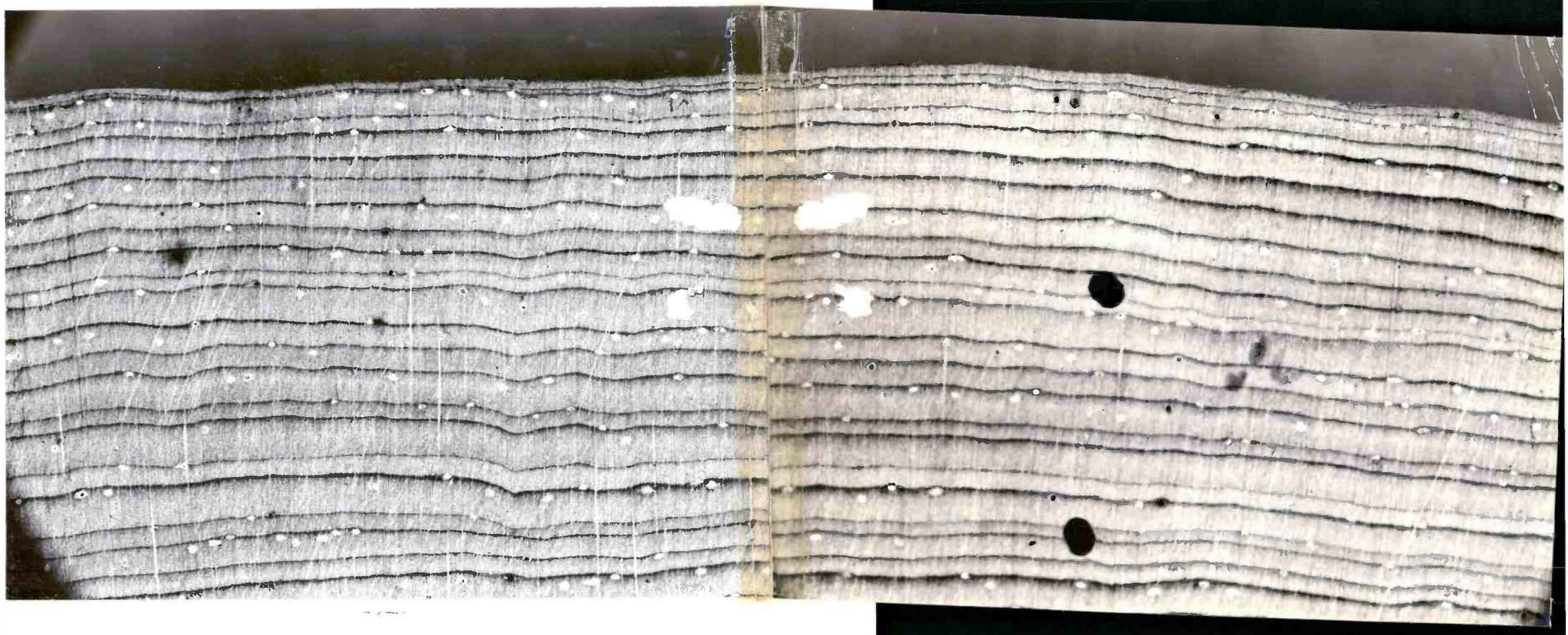

Plate 5A

MAGNIFIED DETAIL OF ANNUAL RINGS IN SECTION A
OF THE CROSS-SECTION OF TREE 39-37.

There is a full complement of annual rings within the section shown by the photographs. Nine rings are found by counting outwards from the upper black spot, which marks the annual layer of 1930. The 1938 ring, however, is very narrow and becomes incomplete or indistinct at one point to the left. Inasmuch as the layers of the years 1933, 1934, and 1935 are relatively broad, the growth pattern of Tree 39-37 since 1930 does not follow the general trend of growth for trees of the Modoc region.

Magnification: x 8.6 diameters; photographs 11249B-1 and 11249B-2 by J. E. Patterson.

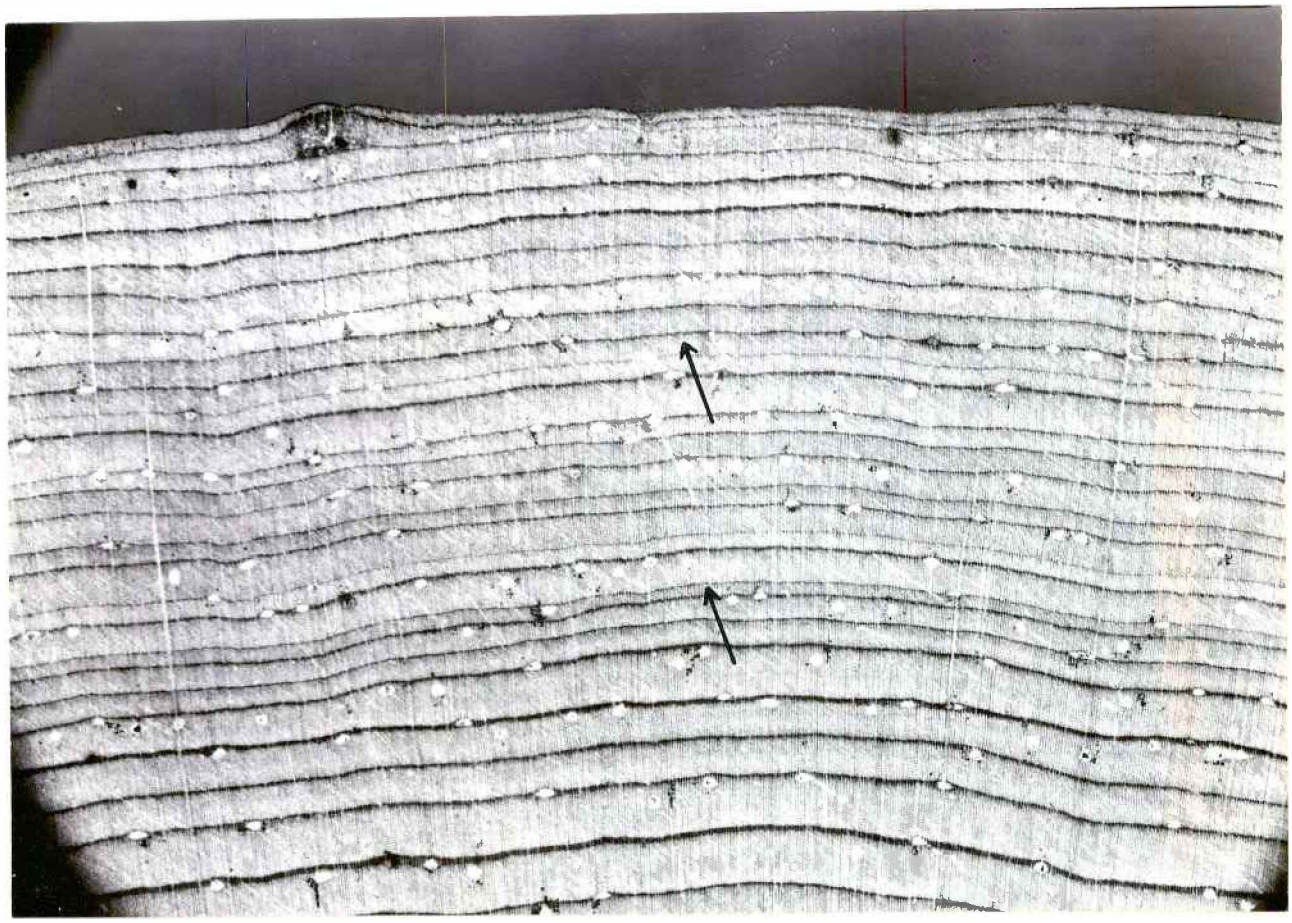

Plate 5B

MAGNIFIED DETAIL OF ANNUAL RINGS IN SECTION B
OF THE CROSS-SECTION OF TREE 39-37.

A full complement of annual layers is shown in this portion of the periphery of the cross-section. Counting outward from the point of the upper arrow, which lies in the 1930 annual layer, nine annual layers are evident. Near the upper left corner a flathead incipient scar is visible in the 1938 annual layer.

The point of the lower arrow lies in the 1920 annual layer.

Magnification: x 8.6 diameters; photograph 11249B-3 by J. E. Patterson.

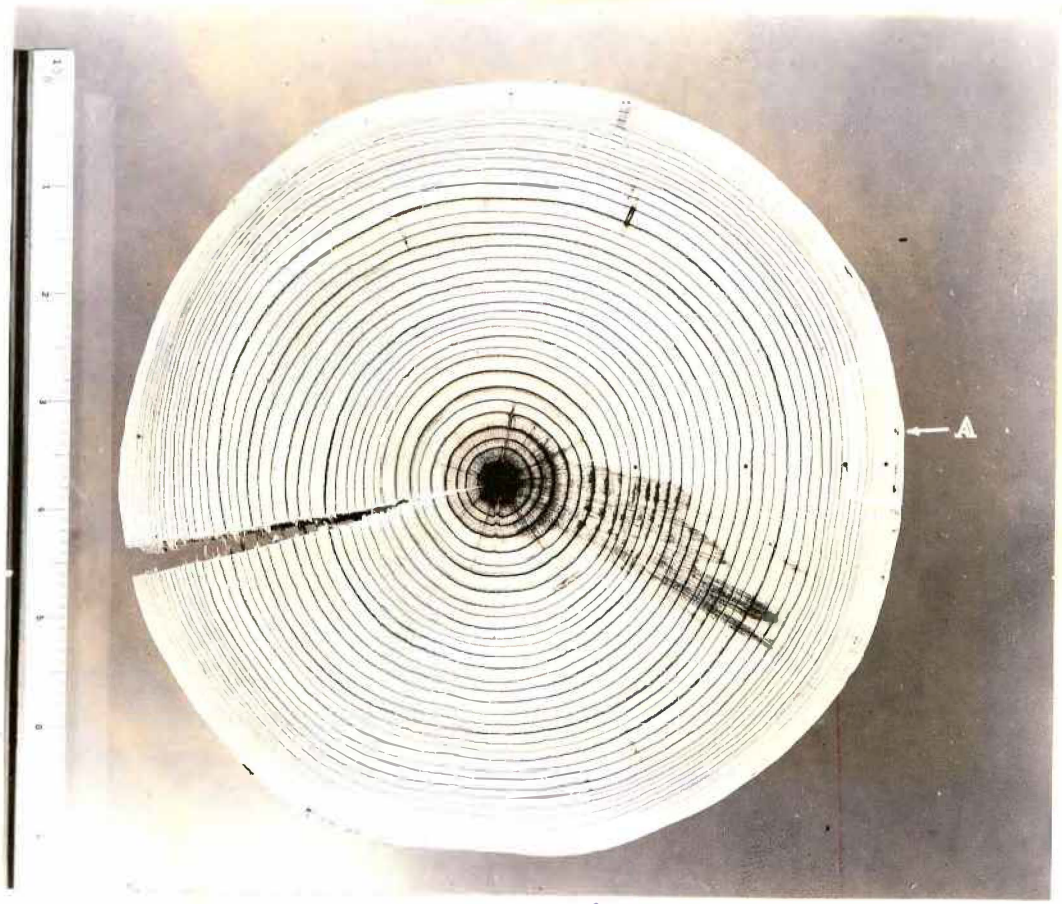

Plate 6.

CROSS-SECTION AT FORTY FEET OF TREE 39-38.
SAMPLES FOR STAINING WERE TAKEN FROM PORTIONS OF THE BOLE ADJACENT TO THE POINT OF CROSS-SECTIONING.

This cross-section showed no missing or incomplete rings during the forty-year interval from 1900 to 1939. Cross-dating of rings with Keen's master sequence was accomplished readily. The narrow outer rings are better illustrated in Plate 7, which shows Section A of the periphery of the cross-section in magnified detail. Flathead attacks have scarred the wood of the last eight to ten years in this tree.

Magnification: x .566 diameters; photograph 11249C by J. E. Patterson.

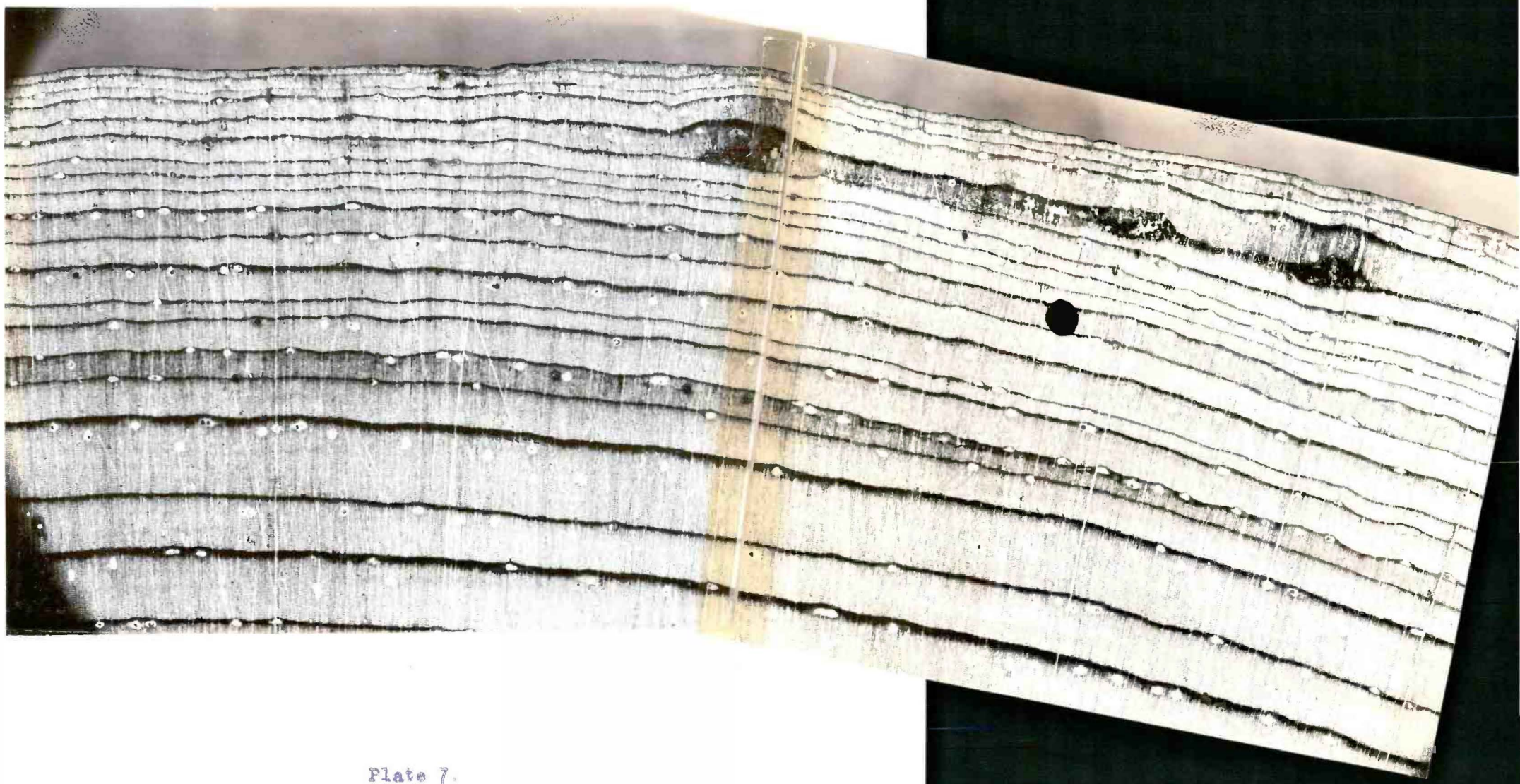

Plate 7.

MAGNIFIED DETAIL OF ANNUAL RINGS IN SECTION A
OF THE CROSS-SECTION OF TREE 39-38.

This view under magnification of Section A of the periphery of the cross-section illustrates the continuous and complete ring complement of tree 39-38. Nine rings are shown above the black spot, which lies on the wood of the 1930 ring. Flathead incipient scars are visible in the 1935 and 1936 wood.

Magnification: x 8.3 diameters; photographs 112490-1 and 112490-2 by J. E. Patterson.

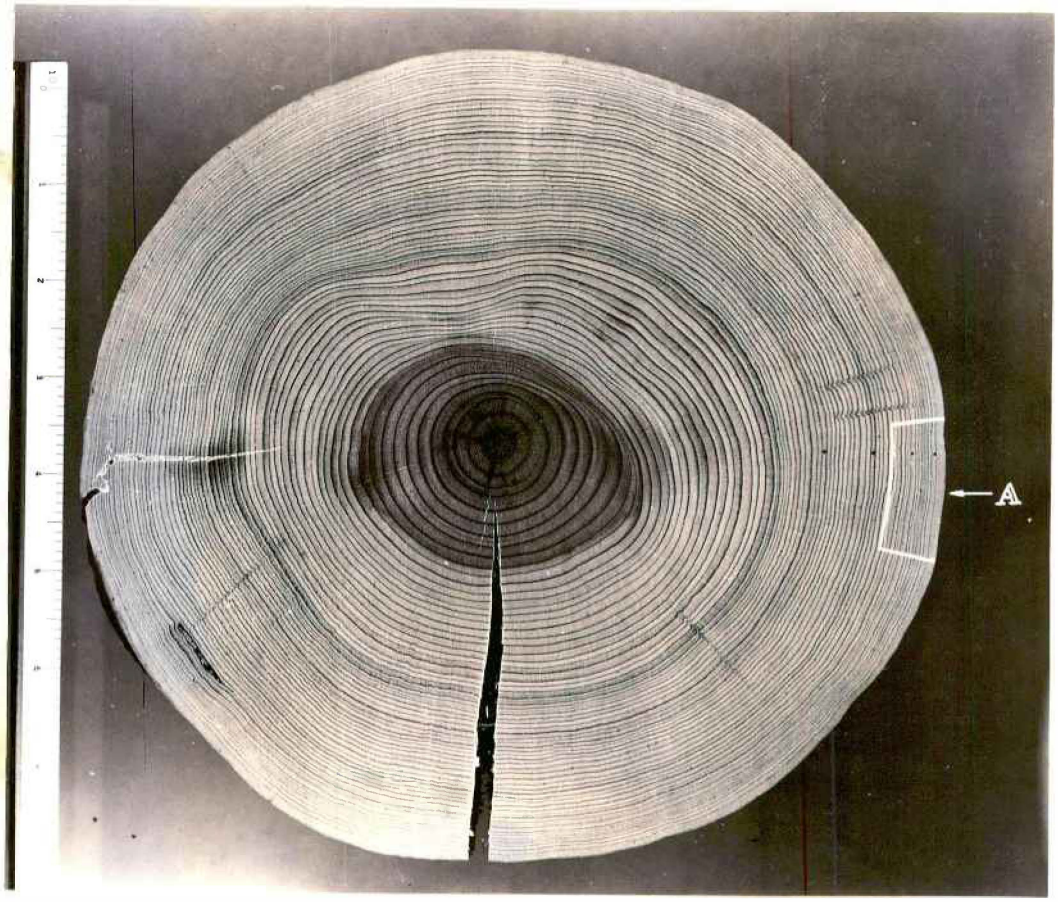

Plate 8.

CROSS-SECTION AT SIXTY FEET OF TREE 39-42.
FROM ADJACENT PARTS OF THE BOLE, SAMPLES WERE TAKEN FOR STAINING.

Although several rings are incomplete at a few points, the rings of the tree were easily identified. No rings are completely missing in this cross-section. The 1932 ring is incomplete at one point; the 1933 layer at two points; the 1935 layer at two points; and the 1939 layer at two points in the periphery of the cross-section. Better detail of the rings of the section A is shown in Plate 9. Flathead attacks are all recent, largely in the last two years, and not readily visible in the photograph.

Magnification, x .507 diameters; photograph 11249D by J. E. Patterson.

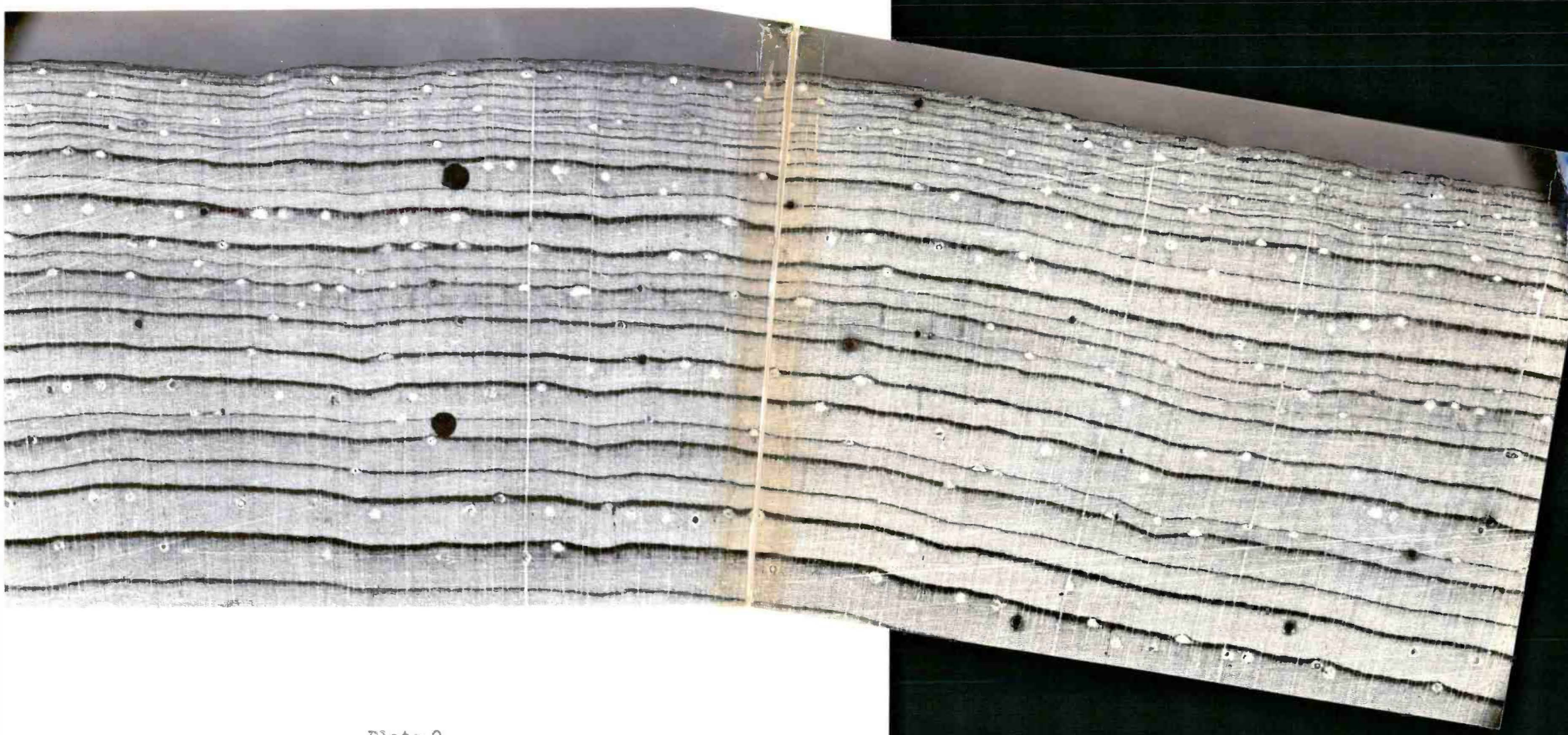

Plate 9.

MAGNIFIED DETAIL OF SECTION A
OF THE CROSS-SECTION OF TREE 39-42.

Counting upward from the upper black spot, which lies on the 1930 ring, nine annual layers are visible and establish the completeness of the growth complement of Tree 39-42. The rings of 1933 and 1935 are very narrow but continuous in this portion of the periphery of the cross-section. The lower black spot lies on the 1920 ring.

Magnifications: x 8.4 diameters; photographs 11249D-1 and 11249D-2 by J. E. Patterson.

Plate 10.

EXPLANATION OF THE FIGURES.

Figure a. A control sample from tree 39-34. This shows the conductive outer zone and unconductive inner zone of wood characteristic of wood of this tree.

Figure b. A sample from tree 39-37. This sample shows the full conductivity for stain characteristic of the wood of this tree.

Figure c. This sample from tree 39-38 was stained in reversed direction, from the morphologically upper end of the sample, to the morphologically lower end of the sample. It shows an outer conductive zone which is somewhat broader than that found in most samples of tree 39-34. This broad outer conductive zone was characteristic for wood samples from tree 39-38.

Figure d. This sample from tree 39-42 shows a very narrow outer conductive zone and a somewhat conductive inner zone. It is representative of the staining behavior of the wood of this tree.

Figure e. This sample is from the vigorous tree 39-43. The wood of this tree is fully conductive for the stain.

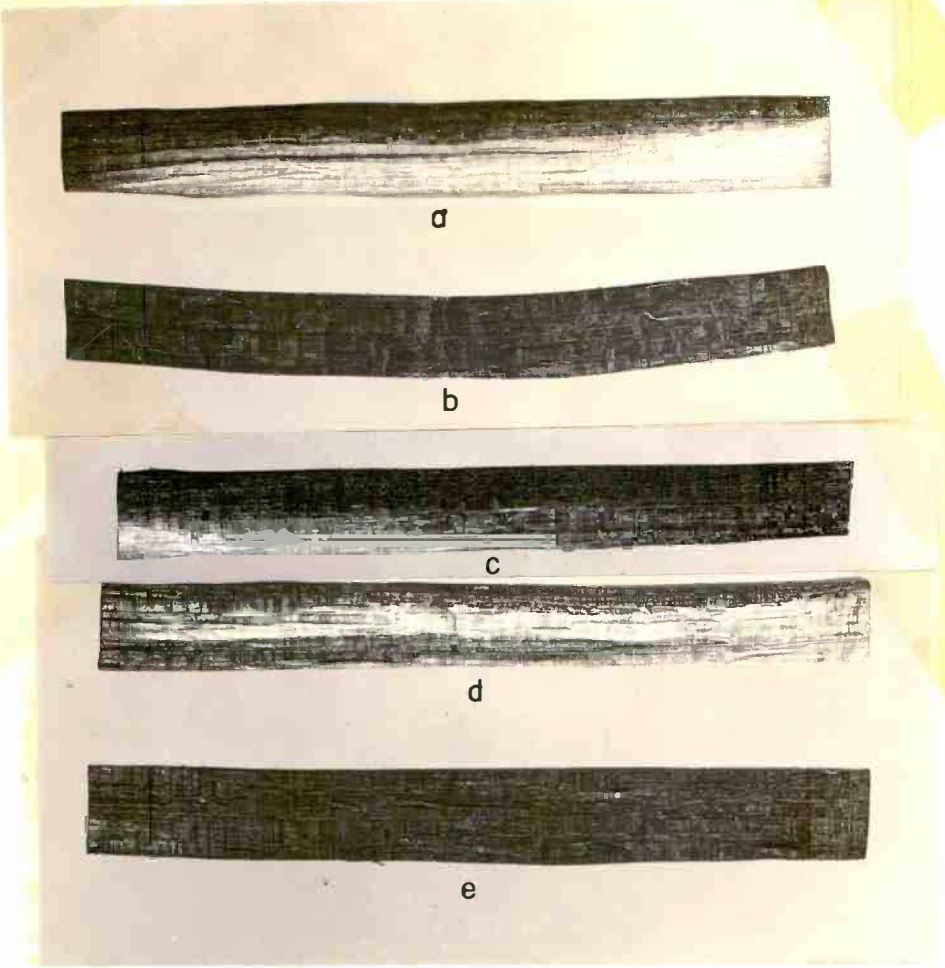

Plate 10.

CONTROL SAMPLES OF THE FIVE TREES THAT WERE USED IN THE CONDUCTION STUDY.

The variations in conduction patterns in the control samples of the five trees used in the conduction study are shown in these figures. From top to bottom of the plate these samples are from trees 39-34, 39-37, 39-38, 39-42, and 39-43. The upper edges of the samples in this plate are the outer cambium surfaces of the samples. The direction of stain movement was from left to right, with the exception of the sample from tree 39-38, figure c. Except in samples of tree 39-38, stain was injected into the samples from the morphologically lower to the morphologically upper ends of the samples. In the samples from tree 39-38, stain was injected in the reverse direction.

Magnification: x 1.33 diameters; photographs 112491 and 112491 by J. E. Patterson.

Plate 11.

EXPLANATION OF FIGURES.

Figure a. An unscarred control sample.

Figure b. A sample with one small flathead scar in 1933 wood. The scar is overgrown by normal wood, and has no apparent effect upon the movement of stain in the outer layers.

Figure c. Four scars are present in this sample. The first small scar is in 1936 wood, and causes local obstruction to stain in wood interior to the scar. The second small scar in 1937 wood has no evident effect. The third scar in 1938 wood blocks out the 1938 and 1939 rings. The fourth scar in 1939 wood is not reached by the stain due to the blocking by the 1938 scar.

Figure d. This sample has two scars. The first scar in 1935 wood seems to retard the stain in 1935 and 1936 rings, preventing the stain from penetrating to the end of the sample. The second scar in 1938 wood blocks out 1938 and 1939 rings

Figure e. Five scars are present in this sample. The first scar in 1937 wood has a retarding effect upon the 1937, 1938, and 1939 rings (not well shown in figure). The second scar in 1936 wood blocks out the 1936 ring. The third scar in 1935 wood blocks out the 1935 layer. The fourth and fifth scars are in 1936 and 1934 wood and beyond the limits of the stain. This sample illustrates the cumulative blocking effects of several scars.

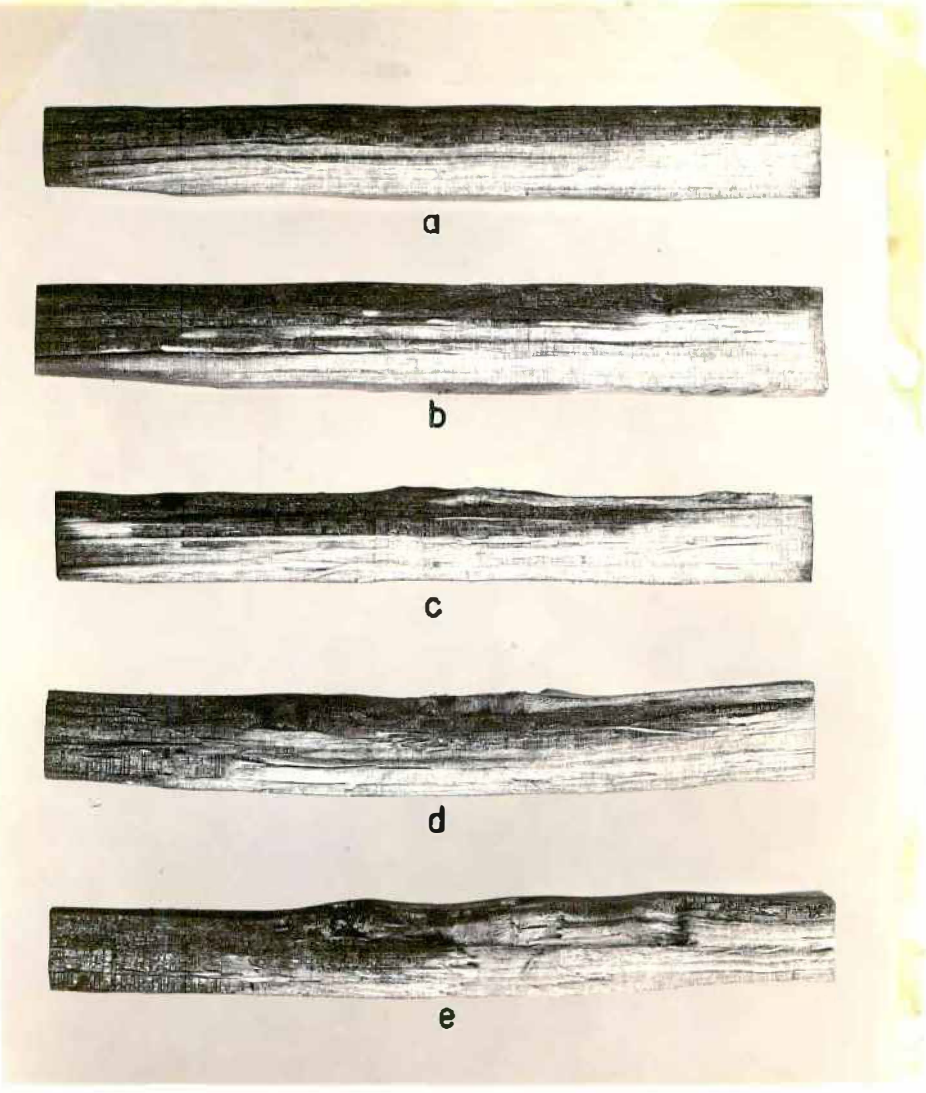

Plate 11

STAINED SAMPLES FROM TREE 39-34.

These five samples show variations in staining due to the absence or presence of flathead scars. The uppermost sample is a control sample, the remainder have one or more scars. Explanation of the plate is given on the opposite page. Stain movement was from left to right.

Because of the tendency of scars to photograph black, and of the pattern created by the grain of the wood, the stained areas are not as clearly differentiated as could be desired. In some cases, also, black areas reflect light, and appear as light patches as if they apparently were unstained.

Magnification: x 1.33 diameters; photograph 11249F by J. E. Patterson.

Plate 12.

EXPLANATION OF FIGURES.

Figure a. This is a control sample with a relatively wide conductive zone, as compared with the control sample shown in figure a, plate 1.

Figure b. Three scars are present. The first in 1937 wood blocks out 1937 and 1938, and retards 1939 so considerably that stain fails to move far into this annual layer. The second scar in 1936 wood blocks out the 1936 annual ring. The third scar in 1938 wood is within the blocked zone. This sample shows cumulative blocking effects of two effective scars.

Figure c. This sample has two small scars in 1936 and 1938 wood. These cause a breakup of stain movement in the outer four layers, but it is not clearly visible in the figure.

Figure d. Four scars are present in the sample. The first in 1933 wood blocks 1933, 1934, and 1935 rings. The second scar in 1929 wood has no apparent effect, as it is in a layer that is only slightly conductive. Scar number 3 in 1932 wood is in a non-conductive layer. Scar number 4 in 1938 wood slightly retards stain penetration into the 1939 layer beyond the scar.

Figure e. Three scars are present in this sample The first is a heavy scar in 1933 wood. It extends to the surface of the sample, blocking seven annual rings, - 1933 to 1939. The second scar in 1932 wood is in an unconductive layer. The third scar in 1939 wood is in the blocked area.

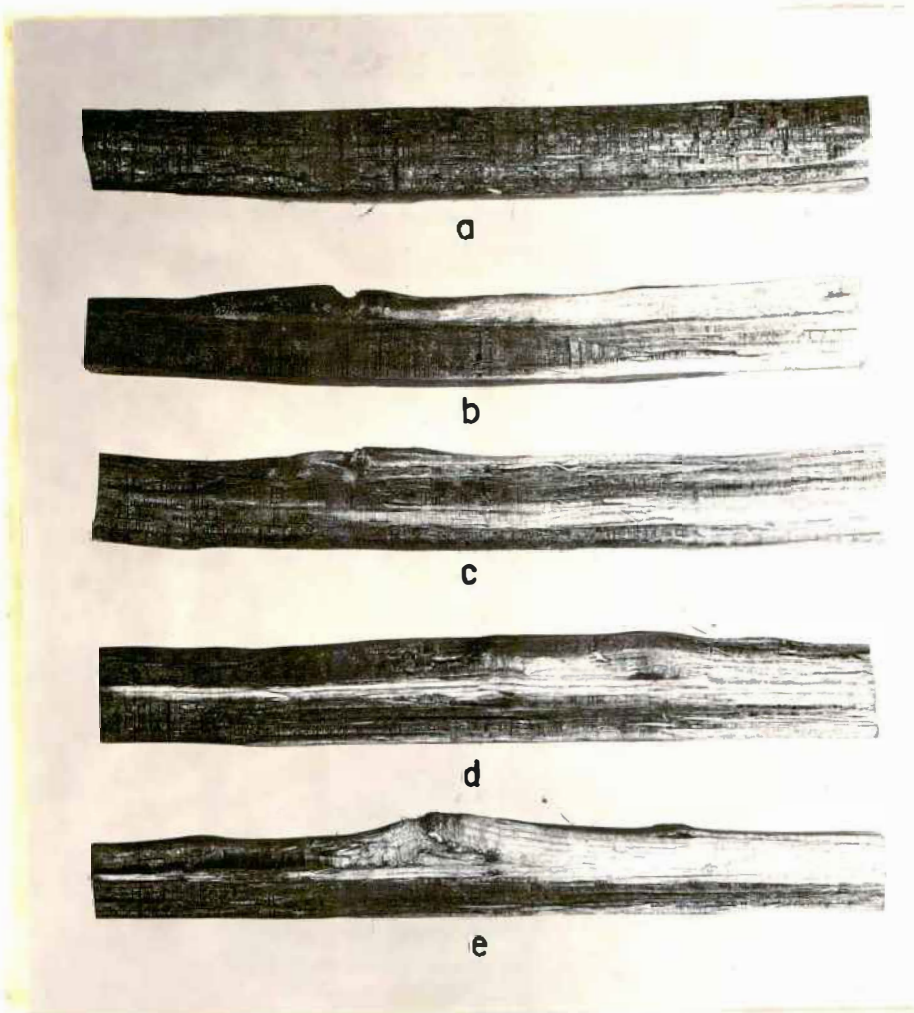

Plate 12.

STAINED SAMPLES FROM TREE 39-34.

These five samples illustrate other variations in amounts of conduction in one control and four scarred samples from tree 39-34. Explanation of the plate is given on the opposite page. Stain movement was from left to right.

Magnification: x 1.33 diameters; photograph 112496 by J. E. Patterson.

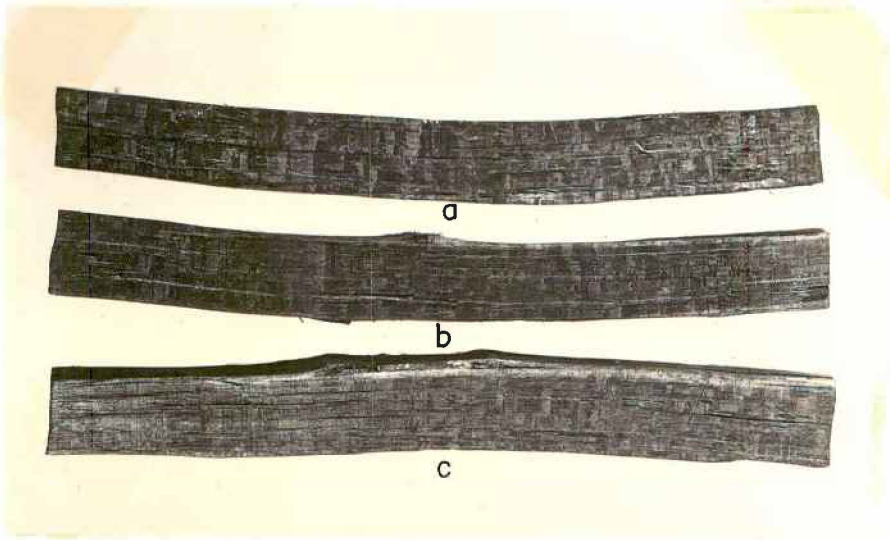

Plate 13.

STAINED SAMPLES FROM TREE 39-37.

Three samples from tree 39-37 show the behavior of the wood of this tree. The wood stained fully throughout the thickness of the control samples. Behind the scars in scarred samples, however, a definite blocking was visible. The highly conductive properties of the wood of this tree made preservation of the pattern somewhat difficult. Stain movement in these samples was from left to right.

EXPLANATION OF FIGURES.

Figure a. A control sample.

Figure b. This is a scarred sample with one scar in 1938 wood. The 1938 and 1939 rings are blocked beyond the scar.

Figure c. This is a scarred sample with two scars. The first scar in 1939 wood causes blocking in the 1937 and 1938 annual layers interior to it. Such a blocking of layers interior to the scar may possibly be due to pitching of these layers following injury of an outer layer. Such pitching of inner layers interior to a scar is often found. The second scar in 1939 wood retards the stain in the 1939 annual layer.

Magnification: x 1.33 diameters; photograph 11249H by J. E. Patterson.

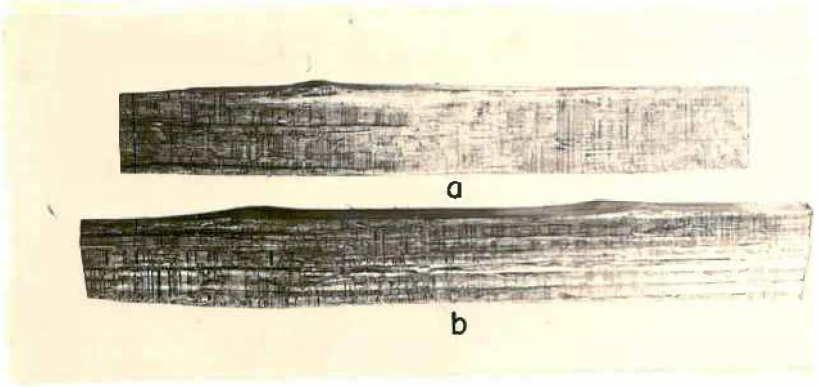

Plate 14.

SAMPLES STAINED WITH SCARLET RED ANILINE STAIN.

Two samples of green wood that were stained with the aniline stain "Scarlet Red". Both of these samples showed well-defined patterns of conducting wood and of blocked areas behind the scars when they were cut open immediately after application of the stain. Continued diffusion of the aniline stain, after treatment obscured the general pattern, and largely obliterated the pattern of blocking due to the scars. The silver nitrate stain gave much sharper and more permanent definition of areas that were functioning as conductors of the stain. Stain movement in these samples was from left to right.

Magnification: x 1.33 diameters; photograph 11249H by J. E. Patterson.

Plate 15.

EXPLANATION OF FIGURES.

Figure a. A control sample for the scarred sample in figure b.

Figure b. A scarred sample with four scars. The first is a small scar in the 1938 ring and causes no blocking. The second scar in 1938 wood blocks out the 1937, 1938, and 1939 rings. The third scar in 1937 wood and fourth in the 1938 wood are in the blocked area and have no effect.

Figure c. A control sample for figure d.

Figure d. This sample has two scars. The first, a long, heavy pitchy scar in 1937 wood runs the length of the sample, - blocking 1937, 1938, and 1939. The inner layers 1936 to 1930 are pitched also. A second scar in 1934 wood is beyond the limits of the stain.

Figure e. A control sample for figures f and g.

Figure f. Seven scars are in this sample. The first in 1936 wood has no evident effect. The second in 1938 wood blocks the 1938 ring and perhaps the 1937. The third in 1938 wood blocks the 1939 ring and reinforces the blocking of 1938 and 1937. The fourth scar in 1938 wood and the fifth scar in 1937 wood are in blocked zone. The sixth and seventh scars in 1935 wood seem to retard the stain in the layer. See text figure 3.

Figure g. Six scars are in this sample. The first in the 1936 ring lies in wood that is pitched and blocked by scar number three. The second scar in the 1933 ring has no effect. The third scar in 1938 wood is large and pitchy, blocking layers 1938 and 1939, and pitching the wood of layers inward to 1933. The fourth scar in 1933 has no effect. The fifth scar in 1936 wood is in blocked wood. The sixth scar in 1927 wood is in unconductive wood.

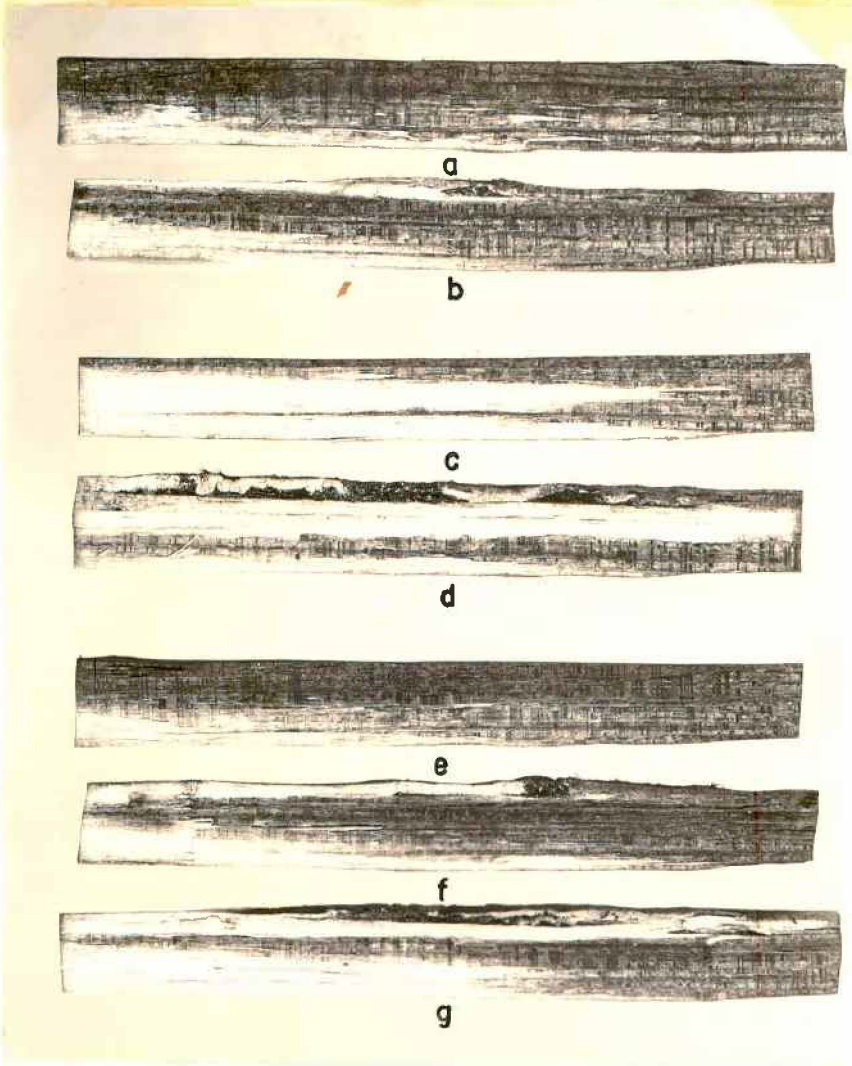

Plate 15.

SAMPLES FROM TREE 39-38,
WHICH WERE STAINED IN A REVERSE DIRECTION.

This plate figures three sets of controls and scarred samples from tree 39-38. These samples were injected from the morphologically upper ends, the stain being forced through the sample in a direction opposite to the normal course of the sap in the wood of the tree. The stain moved from right to left in these figures. Blocking effects no different from those in samples injected in the normal direction were the results of these tests. In both cases, the blocking took place on the side of the scar away from the end where injection was made. It would appear that the scar acts as a physical barrier to the movement of the stain, whether the movement proceeds in one direction or the other. A detailed description of the figures of the plate is given on the opposite page.

Magnification: x 1.33 diameters, photograph 112491 by J. E. Patterson.

Plate 16.

EXPLANATION OF THE FIGURES.

Figure a. Control sample for figure b.

Figure b. A scarred sample with one scar in 1938 wood. This scar blocks rings 1938 and 1939. It also pitches the wood of the 1937 ring, possibly being the reason for no stain movement in the 1937 ring.

Figure c. A control sample for figure d.

Figure d. This scarred sample has two scars. The first scar in 1939 wood has no effect. The second scar in 1938 wood blocks the 1937, 1938, and 1939 rings.

Figure e. A control sample for figure f.

Figure f. Four scars are present in this sample, all in 1938 wood. The first has no effect. The second causes a slight interruption to the stain in the 1938 and 1939 rings. The third scar stops all conduction in these two layers. The fourth scar is in the blocked area. The 1937 layer remains conductive, and is the narrow stripe of stain below the scars.

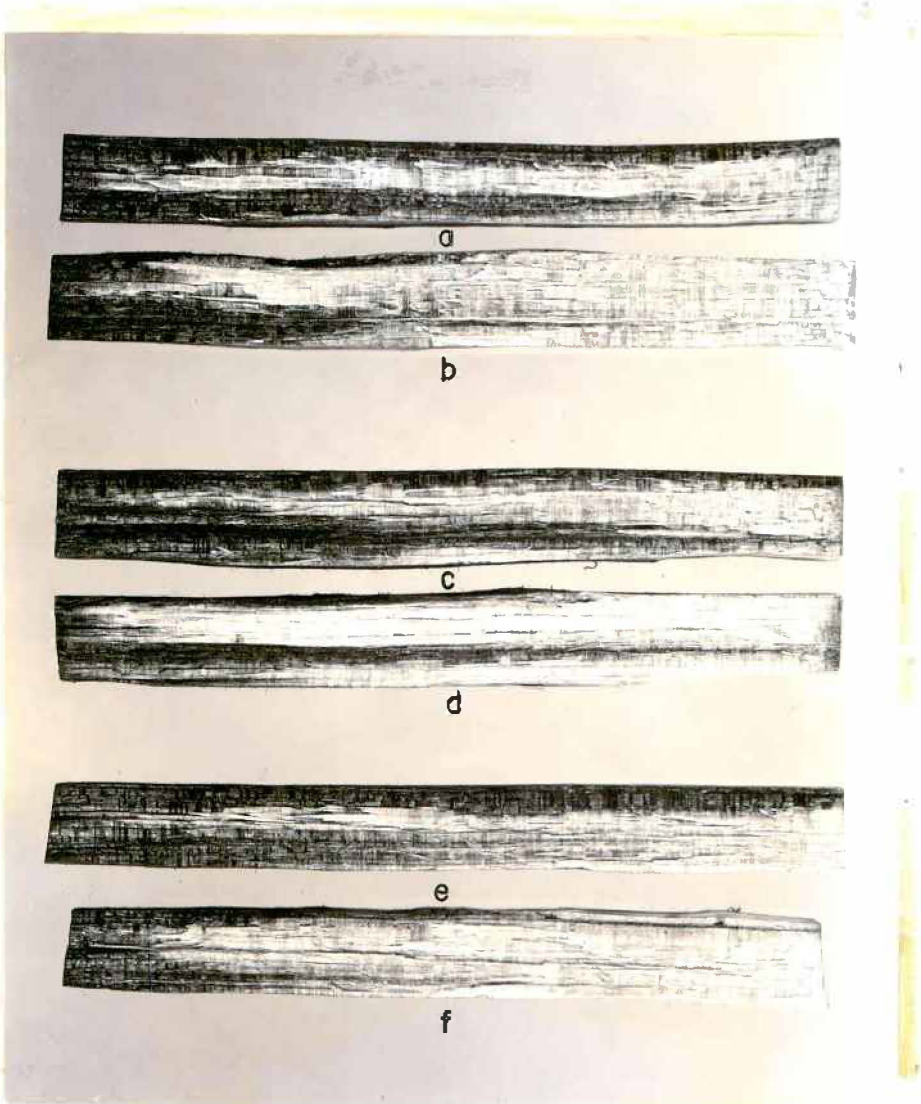

Plate 16.

STAINED SAMPLES FROM TREE 39-42.

Three pairs of control and scarred samples from tree 39-42 are shown above. The uppermost pair were stained immediately after cutting, the middle pair about twenty-eight hours after cutting, and the lower pair about fifty-two hours after cutting. The middle and lower pairs were stored in ice-chilled water until they were treated. No significant changes in staining reaction were apparent between the three groups of samples treated at different intervals following cutting. Most of the samples showed a characteristic pattern with a relatively narrow outer conductive zone, and a narrow inner somewhat conductive zone. The stain moved from left to right through these samples.

Magnification: x 1.33 diameters; photograph 11249J by J. E. Patterson.

Plate 17.

STAINED SAMPLE FROM TREE 39-43.

This stained sample from the healthy, vigorous tree 39-43 is representative of the staining behavior of the wood of this tree. The wood was fully conductive to the stain. The lightly tinted appearance of the right end of the sample is due to light reflection from the black surface of the wood. The right end of the sample was fully stained by the silver nitrate solution. The movement of the stain was from left to right.

Magnification: x 1.33 diameters; photograph 11249H by J. E. Patterson.

SUPPLEMENTARY TREE GROWTH INFORMATION

Year	Tree 39-34, 20 feet					Tree 39-37, 50 feet				
	North	South	East	West	Av.	North	South	East	West	Av.
1939	1.00	.70	.60	.25	.64	.35	.15	.30	.30	.28
1938	1.00	1.05	.75	.55	.84	.15	.00	.00	.20	.09
1937	.90	.55	.35	.50	.58	.55	.40	.45	.60	.50
1936	1.05	.70	.90	.75	.85	.40	.25	.30	.45	.35
1935	.45	.40	.40	.55	.45	.75	.40	.50	.50	.54
1934	.40	.50	.25	.40	.39	.80	.40	.55	.65	.60
1933	.50	.25	.30	.15	.30	.75	.55	.65	.75	.68
1932	1.15	.70	1.00	.85	.93	.65	.45	.50	.60	.55
1931	.90	.65	1.10	.75	.85	.50	.40	.35	.55	.45
1930	1.85	1.95	2.05	1.75	1.90	.65	.35	.30	.55	.46
1929	1.50	1.90	1.80	1.65	1.71	.40	.20	.30	.30	.30
1928	1.40	2.95	2.70	2.40	2.36	.90	.85	.80	.70	.81
1927	1.00	.80	1.35	1.05	1.05	.55	.45	.45	.35	.45
1926	1.00	.80	1.25	1.05	1.03	.45	.45	.40	.45	.44
1925	1.05	.80	1.20	.90	.99	.60	.45	.55	.45	.51
1924	.50	.60	.80	.55	.61	.20	.40	.25	.30	.29
1923	1.65	1.90	2.30	1.90	1.94	.60	.65	.65	.60	.63
1922	1.50	2.35	2.10	1.55	1.90	.40	.40	.15	.40	.34
1921	1.85	2.15	2.45	1.65	2.05	.90	.70	.55	.70	.71
1920	.60	1.00	.95	.65	.80	.40	.30	.20	.30	.30
1919	1.60	1.75	1.75	1.40	1.63	.65	.50	.35	.60	.53
1918	1.50	1.50	1.70	1.40	1.53	.45	.45	.45	.40	.44
1917	2.20	3.25	2.65	2.15	2.56	.75	.85	.85	.80	.81
1916	3.55	4.30	3.90	3.55	3.83	.75	.80	.70	.85	.78
1915	3.00	4.40	3.60	3.55	3.64	.70	.50	.70	.60	.63
1914	2.90	4.10	3.90	3.33	3.56	1.15	.75	1.00	1.00	.98
1913	2.45	3.50	3.40	3.30	3.16	1.05	.80	.95	.95	.94
1912	2.50	3.85	2.60	2.50	2.86	.75	.80	.90	.90	.84
1911	3.05	3.90	2.90	3.20	3.26	1.20	.75	1.10	.95	1.00
1910	2.20	4.30	2.95	3.05	3.13	1.00	.70	1.00	.85	.89
1909	3.35	5.10	4.20	3.60	4.06	1.60	.85	1.45	1.20	1.28
1908	3.80	4.60	4.40	3.70	4.13	1.55	1.00	1.20	1.15	1.23
1907	3.75	3.90	5.35	4.30	4.33	1.30	.95	1.25	1.25	1.19
1906	4.30	1.90	4.35	4.05	3.65	1.05	.80	.80	.80	.86
1905	3.55	4.40	4.15	4.00	4.03	1.15	1.15	1.30	1.05	1.16
1904	4.60	4.55	5.15	4.60	4.73	1.00	.95	1.30	1.00	1.06
1903	4.45	4.30	4.10	4.10	4.24	.60	.80	.95	.75	.78
1902	5.15	4.30	5.15	4.05	4.66	.95	.90	1.10	.95	.98
1901	3.40	3.65	3.43	3.10	3.40	.80	30	1.05	.85	.90
1900	3.10	3.40	3.00	4.00	3.38	1.10	1.00	1.10	.95	1.04

Widths of Annual Rings for Trees 39-34 and 39-37 measured along four radii in the cardinal directions. Measurements made on a cross-section taken from the bole of each tree at the height indicated. Widths of rings expressed in micrometer units. Multiplying these measurements by .89 converts them into millimeters.

	Tree 39-38 40 feet					Tree 39-42 60 feet				
Year	North	South	East	West	Av.	North	South	East	West	Av.
1939	.25	.10	.25	.40	.25	.15	.15	.35	.20	.21
1938	.25	.35	.25	.40	.29	.30	.15	.20	.10	.19
1937	.15	.15	.25	.15	.18	.25	.20	.50	.40	.34
1936	.40	.30	.85	.45	.50	.30	.25	.45	.55	.39
1935	.40	.35	.75	.50	.50	.10	.00	.55	.55	.30
1934	.45	.40	.55	.55	.49	.20	.20	.55	.40	.34
1933	.25	.30	.40	.45	.35	.15	.15	.60	.60	.38
1932	.35	.35	.35	.35	.35	.35	.30	.60	.55	.45
1931	.40	.35	.45	.50	.43	.40	.35	.50	.40	.41
1930	.65	.50	.65	.70	.63	.60	.75	.55	.60	.63
1929	.70	.65	.75	.85	.74	.65	.60	.40	.60	.56
1928	.85	.60	.95	.85	.81	1.00	.80	.80	.60	.80
1927	.40	.45	.40	.55	.45	.45	.55	.45	.40	.46
1926	.75	.65	1.00	.90	.83	.50	.40	.40	.40	.43
1925	.85	.50	.55	.61	.61	.55	.60	.55	.50	.55
1924	.85	.75	.90	.80	.83	.45	.30	.30	.25	.33
1923	1.75	1.40	1.90	1.45	1.63	1.00	.85	.55	.60	.75
1922	1.30	1.10	1.45	1.15	1.25	.85	.60	.40	.40	.56
1921	1.70	1.85	1.85	1.70	1.78	.95	.85	.65	.55	.75
1920	1.40	1.70	1.35	1.10	1.39	.60	.35	.35	.40	.43
1919	1.45	1.20	1.45	1.40	1.38	.75	.75	.55	.60	.66
1918	1.70	1.15	1.40	1.15	1.35	.80	.65	.40	.60	.61
1917	2.55	2.20	2.35	2.05	2.29	1.35	1.20	.55	1.05	1.04
1916	2.95	2.60	2.30	2.35	2.55	1.30	1.05	.70	.90	.99
1915	3.30	2.15	2.70	1.95	2.53	1.20	1.00	.55	.95	.93
1914	4.35	2.75	3.60	3.10	3.45	1.70	1.50	.85	1.15	1.30
1913	3.80	2.40	3.35	2.60	3.04	1.30	1.25	.90	1.05	1.13
1912	2.85	2.05	2.75	2.20	2.46	1.20	1.10	.70	.90	.98
1911	3.25	2.55	3.25	2.65	2.93	1.45	1.05	.75	1.25	1.13
1910	3.10	2.75	3.40	2.80	3.01	1.35	1.20	.80	1.05	1.10
1909	3.25	2.35	3.35	3.35	3.08	1.45	1.35	.80	1.70	1.33
1908	3.25	3.10	3.15	3.60	3.28	1.75	1.50	1.00	1.55	1.45
1907	3.15	2.90	2.90	3.10	3.01	1.75	1.95	.90	1.20	1.45
1906	3.00	3.40	2.80	3.15	3.09	1.60	1.45	.85	1.10	1.25
1905	2.60	3.50	2.95	3.85	3.23	1.60	1.65	1.15	1.45	1.45
1904	2.30	2.90	2.95	2.90	2.76	1.30	1.35	1.00	1.40	1.26
1903	2.05	2.55	3.05	2.95	2.65	1.35	1.50	.65	1.00	1.13
1902	2.20	2.10	2.45	2.15	2.23	1.15	1.15	.85	1.25	1.10
1901	2.45	2.45	2.40	2.40	2.43	1.35	.95	.65	1.25	1.05
1900	2.95	3.30	2.70	2.75	2.93	1.40	1.30	.90	1.40	1.25

Widths of Annual Rings for Trees 39-37 and 39-38 measured along four radii in the cardinal diredtions. Measurements made on a cross-section taken from the bole of each tree at the height indicated. Widths of rings expressed in micrometer units. Multiplying these measurements by .89 converts them into millimeters.

Tree 39-43
Breast Height

Year	North	South	Average
1939	1.00	1.05	1.03
1938	1.00	1.15	1.08
1937	.60	.70	.65
1936	.80	.70	.75
1935	.75	.80	.78
1934	.70	.70	.70
1933	.50	.35	.43
1932	.50	.55	.53
1931	.50	.70	.60
1930	.75	.95	.85
1929	.60	.85	.73
1928	.70	1.10	.90
1927	.60	.60	.60
1926	.60	.90	.75
1925	.60	.85	.73
1924	.20	.35	.28
1923	.70	.50	.60
1922	.50	.70	.60
1921	1.05	.90	.98
1920	.65	.80	.73
1919	.80	.90	.85
1918	.80	1.00	90
1917	.90	1.30	1.10
1916	1.35	1.50	1.43
1915	1.20	1.50	1.35
1914	.70	.95	.83
1913	1.20	1.35	1.28
1912	1.30	1.10	1.20
1911	.90	1.45	.78
1910	1.05	1.40	1.23
1909	1.55	1.90	1.73
1908	1.90	2.50	2.20
1907	2.10	2.75	2.43
1906	1.35	1.75	1.55
1905	1.45	2.00	1.73
1904	1.75	2.25	2.00
1903	2.10	2.15	2.13
1902	2.05	2.15	2.10
1901	1.95	1.95	1.95
1900	1.10	1.90	1.50

Widths of Annual Rings for Tree 39-43 measured along two cores taken on north and south sides of the tree at Breast Height. Widths of rings expressed in micrometer units. Multiplying these measurements by .89 converts them into millimeters.